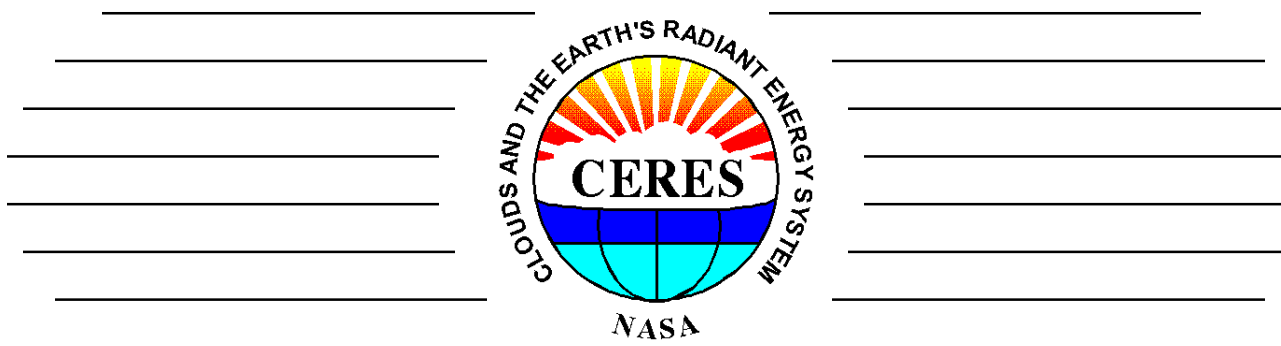




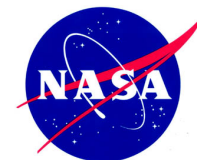
CERES Instrument Status

Flight Models 1 -6 (FM1 – FM6)



Susan Thomas
CERES Instrument Working Group Team

CERES Science Team Meeting
NASA Langley Research Center
Hampton, Virginia
May 7 - 9, 2019



Instrument Working Group

WG Chair: Kory Priestley

Instrument Operations

- B. Mike Tafazoli -
Janet Daniels
Christopher Brown
John Butler
Alexander Thickstun
Adam Horn
Carol Kelly
William Edmonds

Data Management

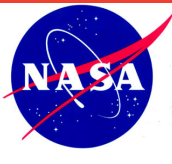
- Denise Cooper -
- Dale Walikainen -
A. Thomas Grepiotis
Mark Timcoe
Dianne Snyder

Science

-Susan Thomas-
Phillip Hess
Hyung Lee
Mohan Shankar
Nathaniel Smith
Nitchie Smith
Z. Peter Szewczyk
Robert Wilson



CERES Instrument Working Group



CERES Instrument Operations: FM1 - 6

CERES Instruments, Flight Models 1- 6 (FM1 – FM6) are in nominal mode of operation.

Inter-comparison Operations planned for Summer 2019

Data Collect at over-pass region of 70 degree N

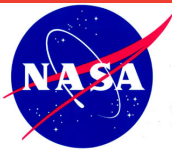
CERES Terra/FM1 – S-NPP/FM5: May 1 – July 31, 2019.

CERES Terra/FM1 – NOAA-20/FM6: May 1 – July 31, 2019.

CERES Terra/FM1 – Aqua/FM3: June 1 – 30, 2019

Data collect 60 N – 0 (Equator)

CERES Terra/FM2 – GERB: June 1 – June 30, 2019



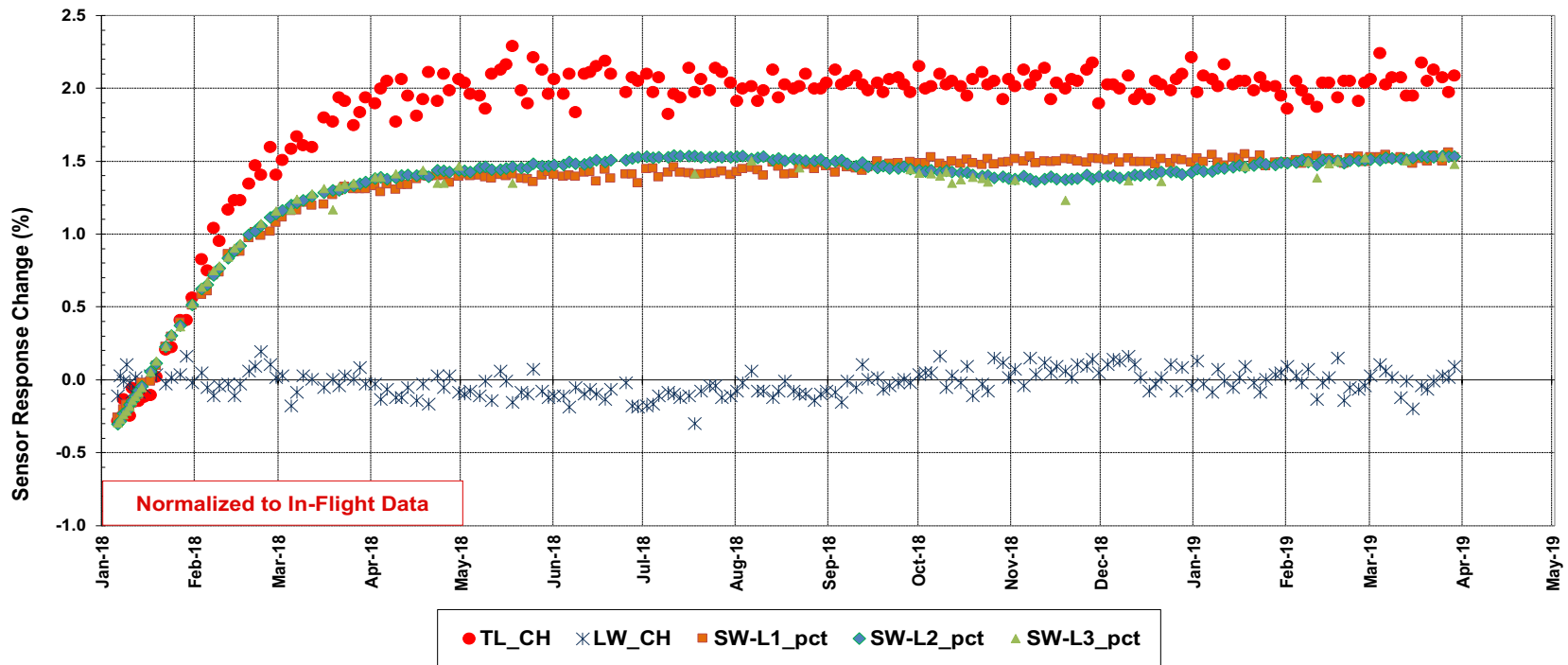
NOAA-20/CERES FM6 INSTRUMENT STATUS

- 1. Calibration: ICM and Solar**
- 2. Validation: Tropical Mean**
- 3. Intercomparisons**

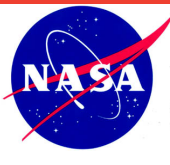


NOAA-20/CERES FM6 Calibration - ICM

Calibration results using on-board sources (Blackbodies and SW Lamp) show a response increase of 2.3% for Total and 1.8% for Shortwave sensors from start of mission. Both sensors stabilized after 3 months in mission. Response from Longwave sensor do not show variation.

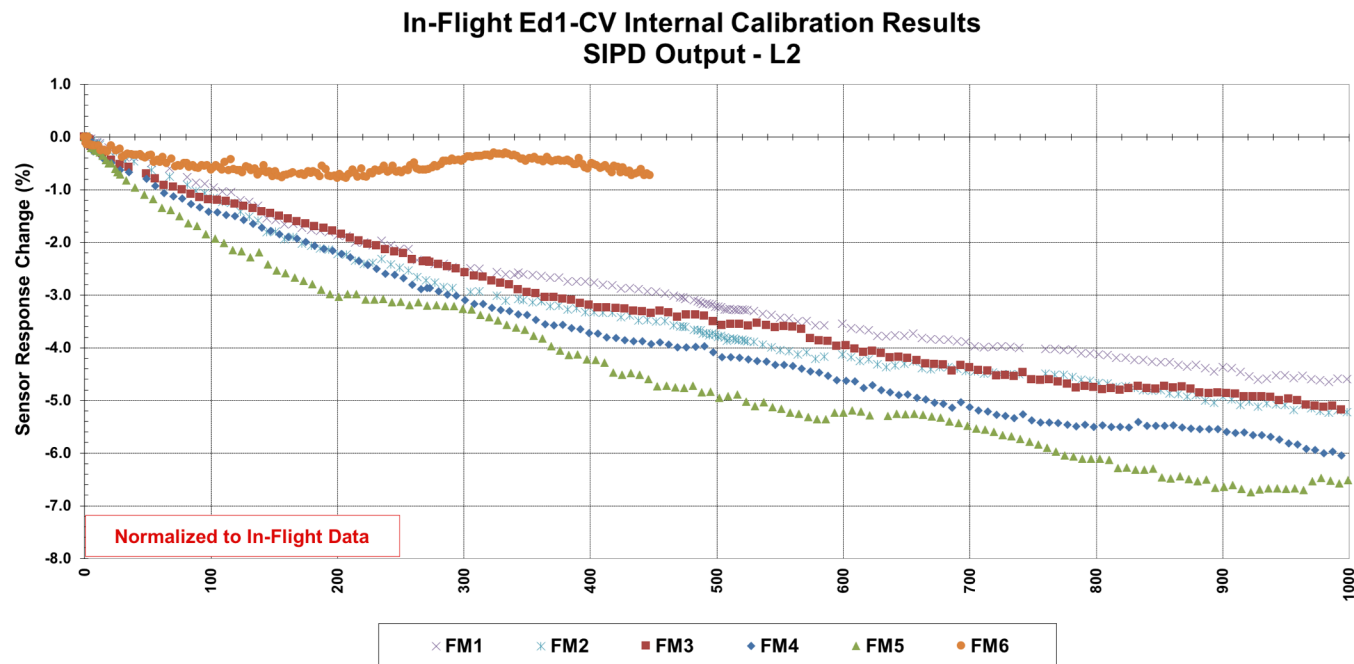


CERES Instrument Working Group



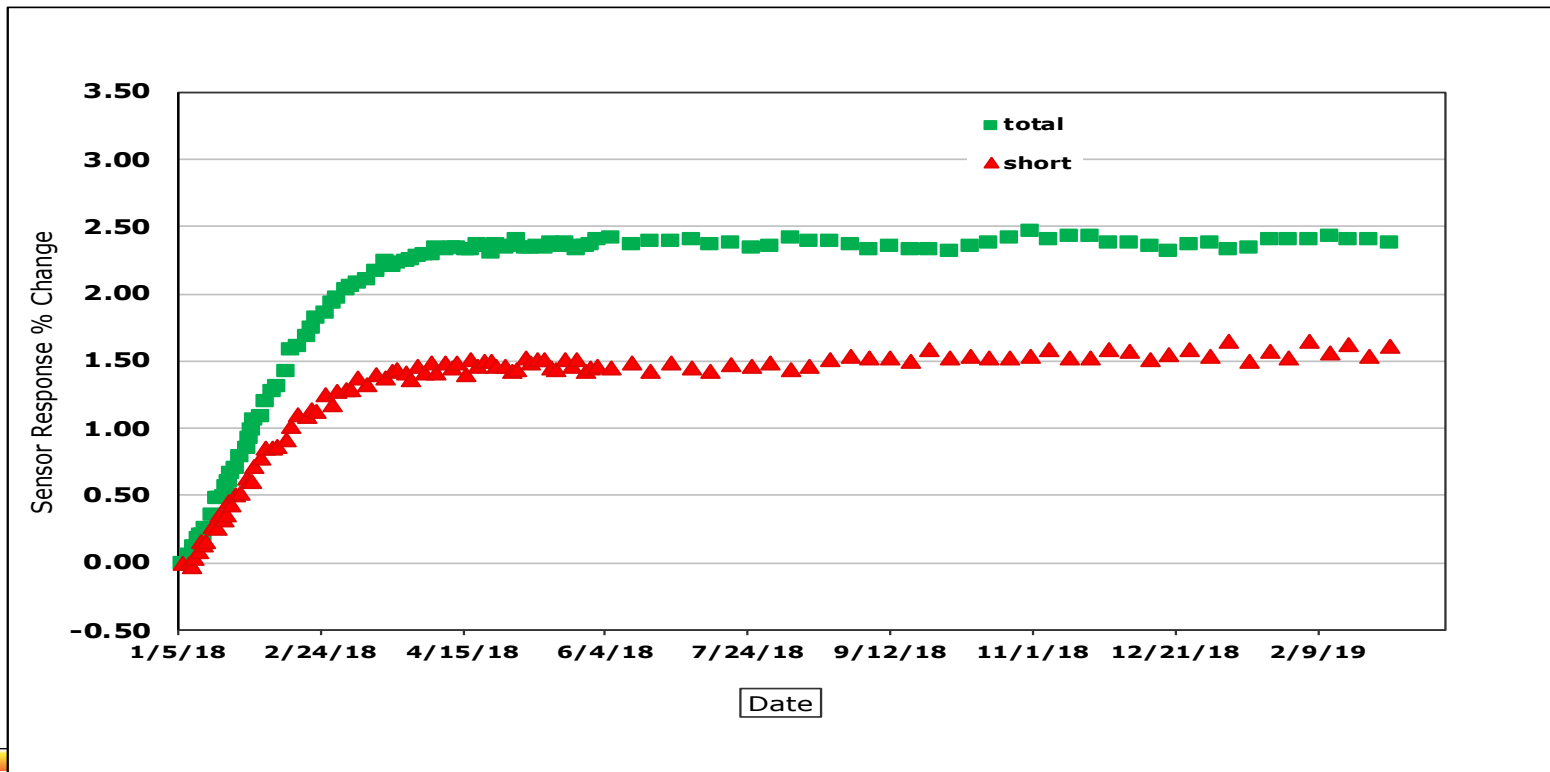
NOAA-20/CERES FM6 Calibration - ICM

SWICS - Silicon Photodiode, the independent monitor for the SW Lamp source shows tremendous improvement in it's on-orbit performance when compared with previous instruments.



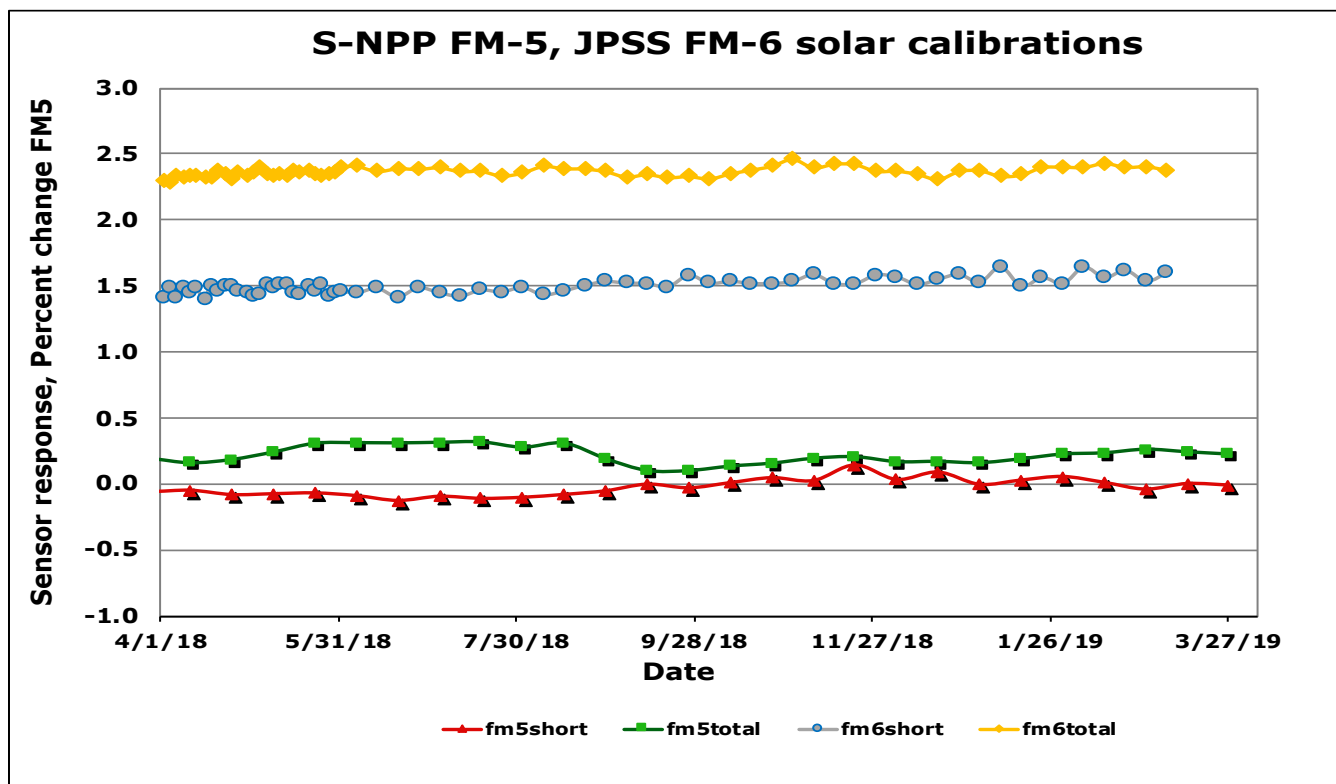
NOAA-20/CERES FM6 Calibration - Solar

Solar calibration results using the Solar diffuser – Mirror Attenuator Mosaic (MAM) show similar response trend as observed with on-board calibration sources. Total sensor response rise is 2.4% and Shortwave sensor increase is 1.5%. The response stabilized after 3 months in mission.



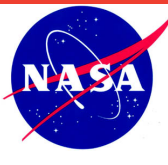
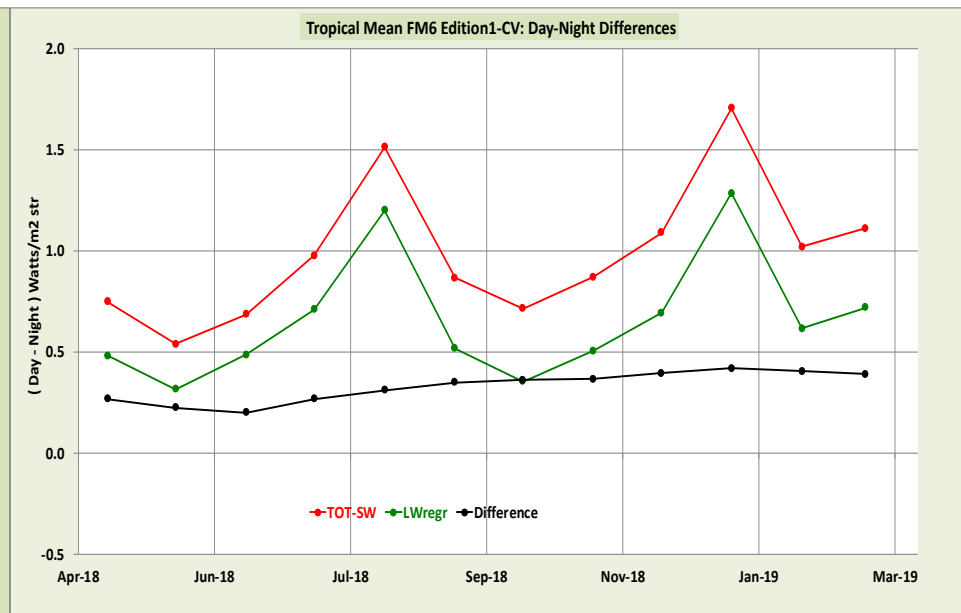
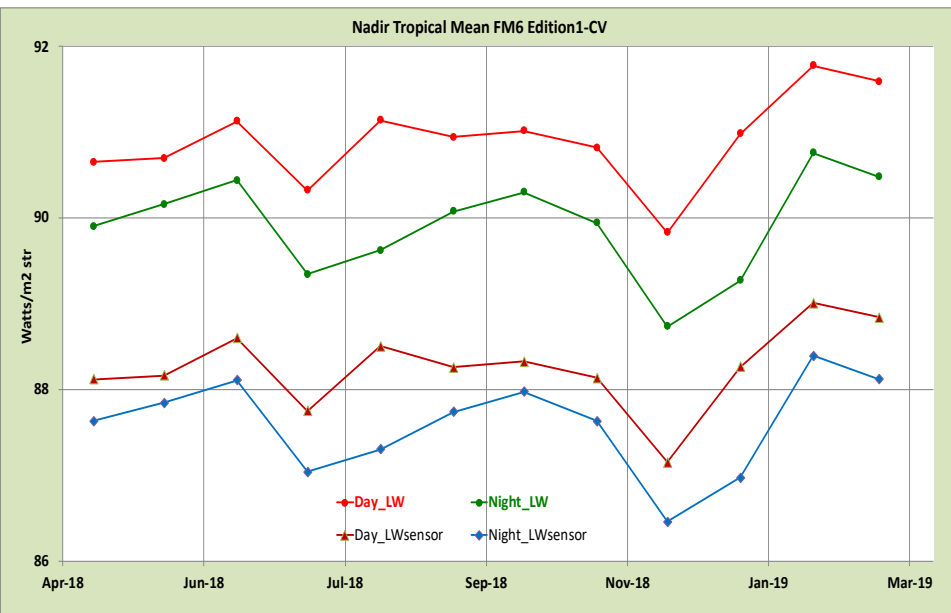
NOAA-20/CERES FM6 Calibration - Solar

Comparison with S-NPP/FM5 solar calibration results show the MAMs on FM6 instrument are stable.



NOAA-20/CERES FM6 Validation – Tropical Mean

Tropical Mean (TM): Nadir LW radiance for All-sky Ocean in ± 20 deg Latitude.
Day and Night TM values from both Total and Longwave channels are trended.
Changes in SW/TOT channel is monitored through Day-Night (DN) Difference comparison between LW measurements from Total sensor and LW sensor.



NOAA-20/FM6 – Aqua/FM3 INTERCOMPARISON

Simultaneous Earth observation with Aqua/FM3

May – December 2018

$\Delta\text{Time} < 1\text{min}$; $\Delta\text{RAZ} < 10^\circ$; $\Delta\text{VZA} < 10^\circ$

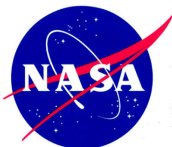
All-sky

(FM6-FM3)/FM6	FM6 Radiance [W m ⁻² sr ⁻¹]	Relative Error [%]	α -confidence [95%]	Number of samples
Shortwave	79 /88	3.34 / 3.67	.6 /.5	22/30
LW daytime	76 /76	1.95 /1.18	.2 /.1	23/31
LW nighttime	66 /68	1.97/1.90	.2 /.1	22/42

- Edition 1-CV for FM6 and Edition 4 for FM3 are used
- Shown differences are computed as “average of differences” to avoid error cancellation



CERES Instrument Working Group



NOAA-20/FM6 – Terra/FM1 INTERCOMPARISON

Minor Plane Radiance Measurement:

FM1 and FM6 align their scans in a plane perpendicular to local solar plane.

Location: 70° N Time differential for FM1 - FM6 < 10 min every 64 hours.

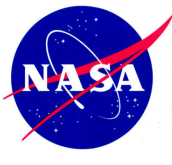
May – July 2018

$\Delta\text{RAZ} < 10^\circ$; $\Delta\text{VZA} < 10^\circ$

All-sky

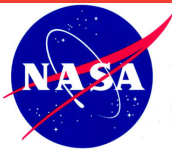
(FM6-FM1)/FM6	FM6 Radiance [W m ⁻² sr ⁻¹]	Relative Error [%]	α -confidence [95%]	Number of samples
Shortwave	110	1.50	.16	143
LW daytime	77	2.15	.07	147

- Edition 1-CV for FM6 and Edition 4 for FM1 are used
- Shown differences are computed as “average of differences” to avoid error cancellation



S-NPP/ CERES FM5 INSTRUMENT STATUS

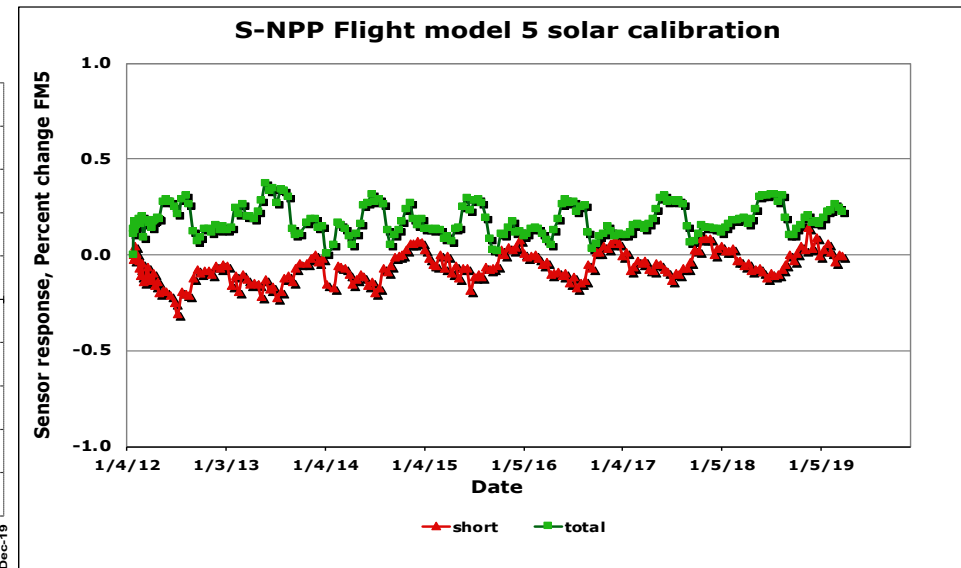
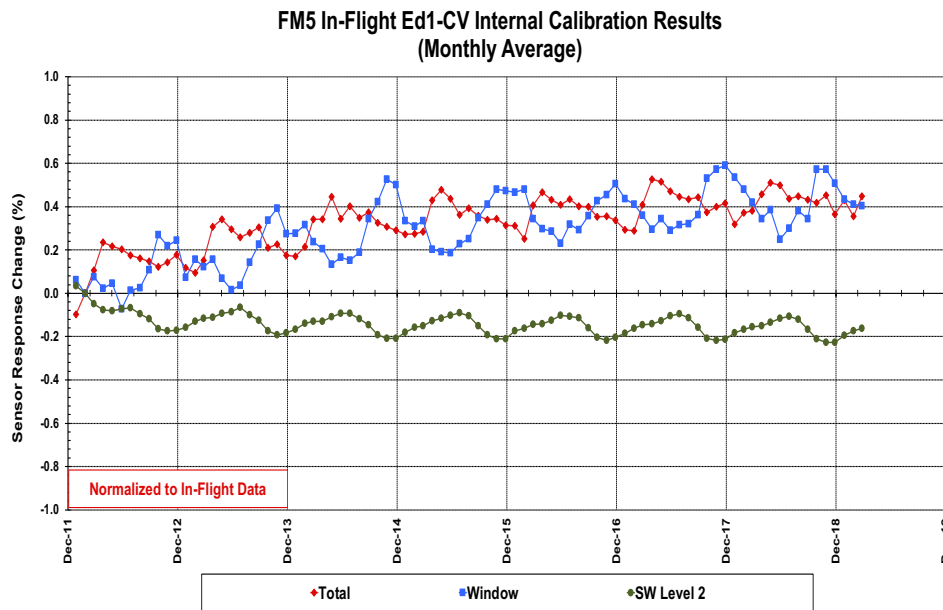
- 1. Calibration: ICM and Solar**
- 2. Validation Results**
- 3. Edition-2 Evaluation**
- 4. RAP Operation Planning**



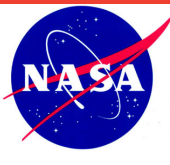
S-NPP CERES FM5 Instrument Calibration

ICM calibration: Increase in response of 0.5% for Total and 0.6% for Window sensor. SW sensor shows a drop of 0.2 percent.

Solar calibration: Total sensor response remain steady. SW sensor show increase in trend of 0.1%.

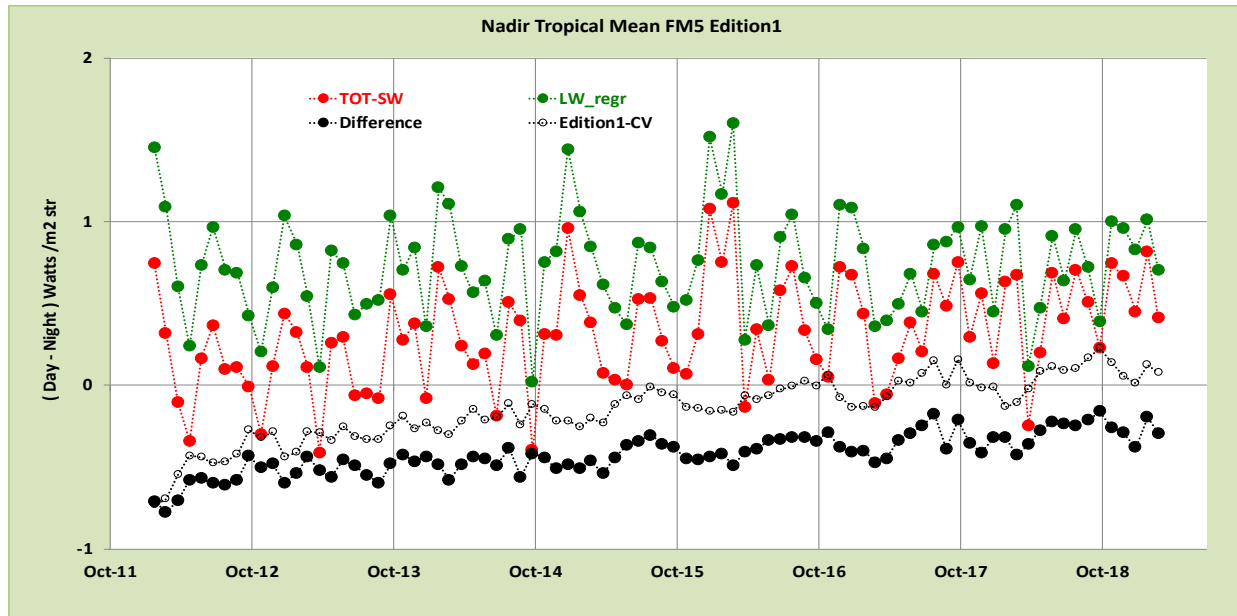


Sensor gain corrections based on ICM calibrations are applied to Edition1 data products.

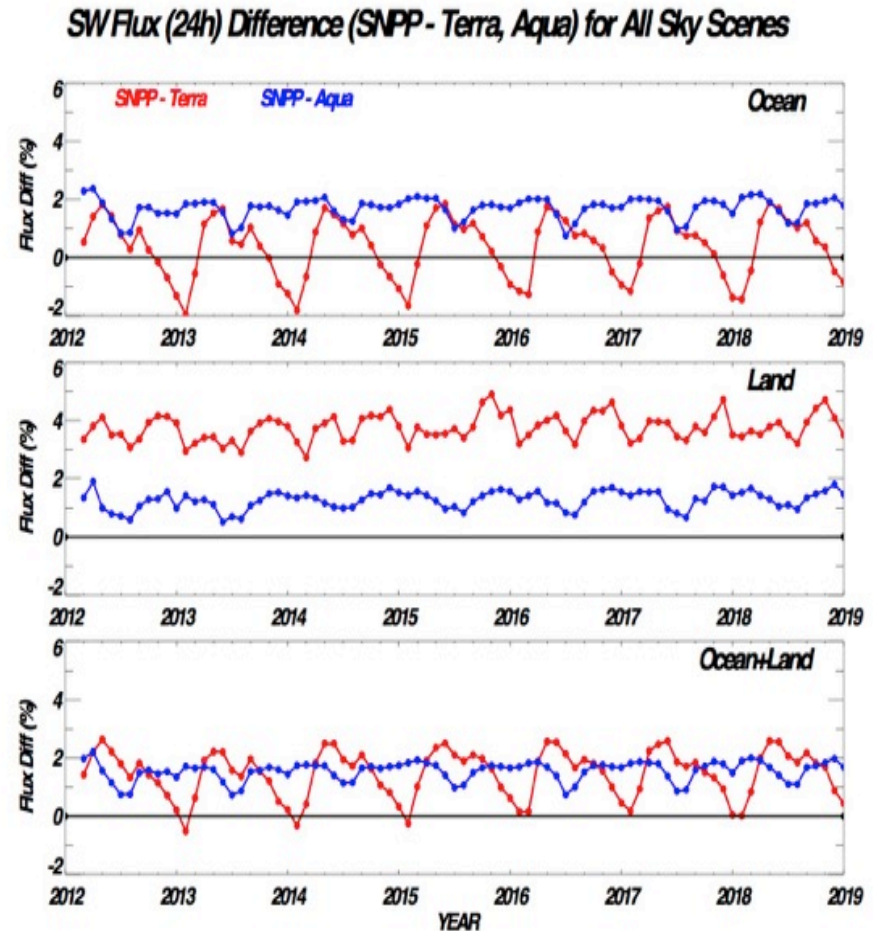
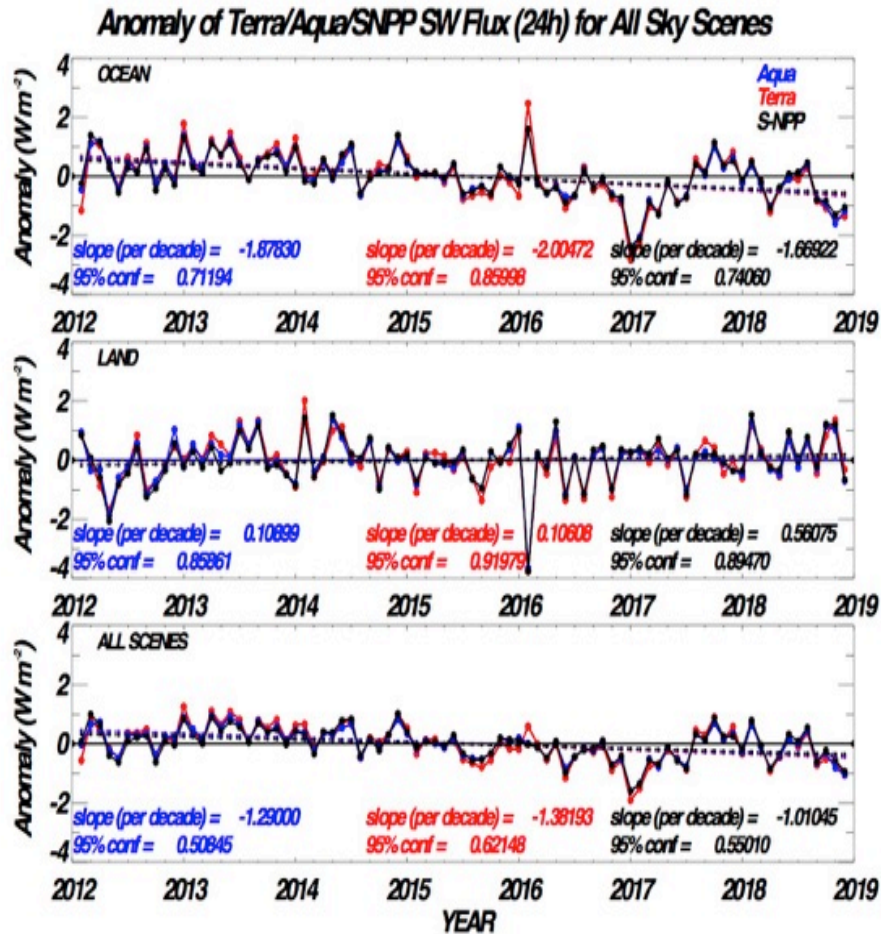


S-NPP/CERES FM5 Validation Results

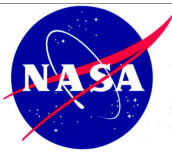
Tropical Mean (TM): Nadir LW radiance for All-sky Ocean in ± 20 deg Latitude.
Day-Night (DN) Difference comparison between LW and Simulated LW from Window measurements is used to monitor changes in SW portion of TOT sensor.
DN Difference radiance of FM5 Edition1 show a positive trend of $< 0.01 \text{ W/m}^2\text{sr}$ per year, which can attribute to minor changes in SW/TOT sensor.



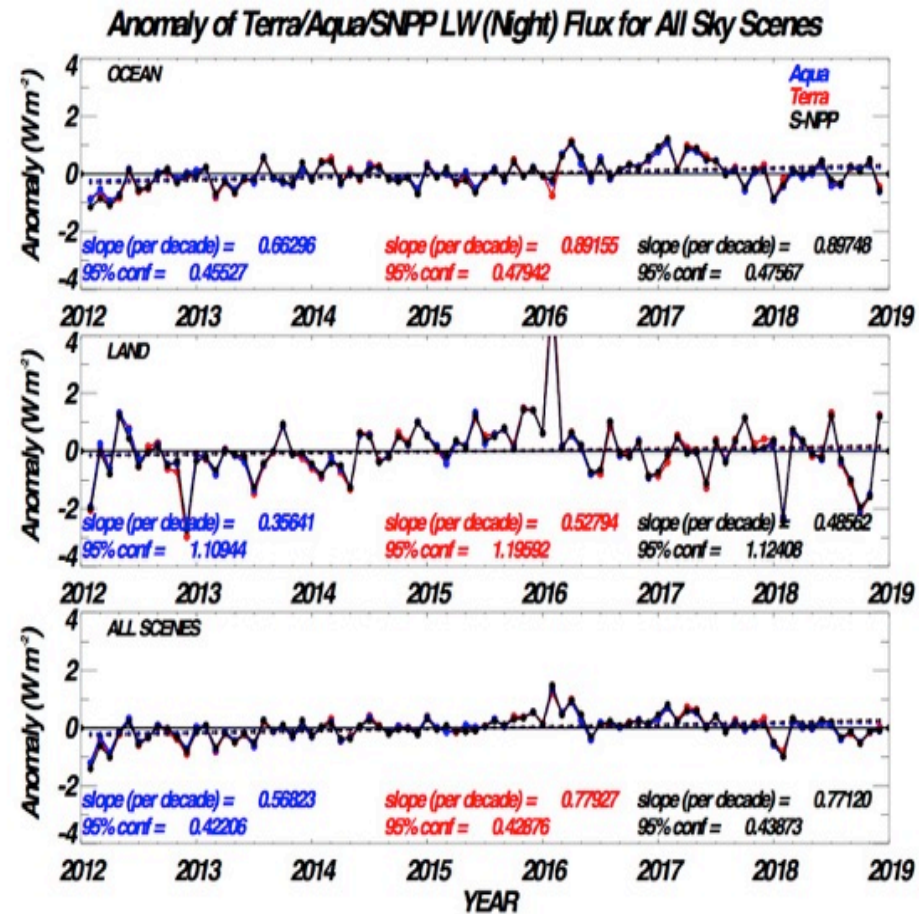
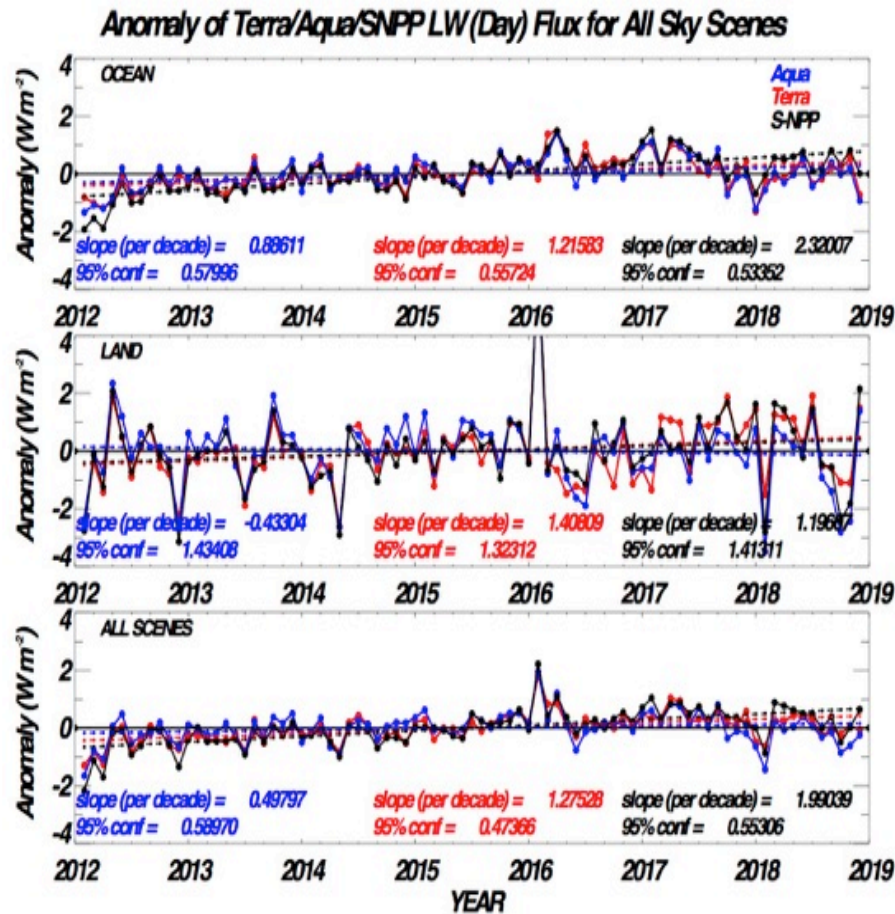
S-NPP/FM5, TERRA & AQUA COMPARE: SW



SW Flux anomaly for all scenes show similar trend for all instruments.
S-NPP/FM5 SW difference with Terra/FM1 and Aqua/FM3 hold stable.



S-NPP/FM5, TERRA & AQUA COMPARE: LW



LW-Day and LW_Night anomaly trends for all scenes show similar trend for S-NPP/FM5, Terra/FM1 and Aqua/FM3 instruments.

Edition2 S-NPP/FM5 -Radiometric Scaling

- The intercomparison results between Edition1 S-NPP/FM5 and Edition4 Aqua/FM3 showed that SW radiances are higher for FM5 instrument.
- FM5 instrument test data from pre-launch Shortwave calibration with SWRS was revaluated for both SW sensor and Total sensor (SW/TOT).
- Sensor measurement uncertainty at each discrete spectral wavelength used in SWRS calibration was determined.
- The derived SW SRF was used to calculate the reflectance for FM5 instrument.
- SW reflectance inter-comparisons for 2014 was used to determine the overall difference between NPP/FM5 and Aqua/FM3 for radiometric scaling.
- A Lagrange multiplier based optimization process was applied to determine the solution within the measurement uncertainties that provide better agreement for global all-sky SW measurement between FM5 and FM3.



S-NPP/FM5 SRF Evaluation

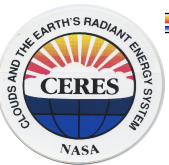
Impact of Lagrange solution SRF to SW reflectance

2014 SW Reflectance comparison with the Pre-launch SW SRF

	FM3 (Reflectance)	FM5- SV01 (Reflectance)	% Diff
All-sky all scenes	0.2936	0.2947	0.3868
Clear Ocean	0.0606	0.0611	0.7370
Clear Land	0.2181	0.2184	0.1053

2014 Edition-2 BOM SW Reflectance Comparison

	FM3 (Reflectance)	FM5- SV02 (Reflectance)	% Diff
All-sky all scenes	0.2936	0.2936	0.0000
Clear Ocean	0.0606	0.0605	-0.1884
Clear Land	0.2181	0.2176	-0.2256



S-NPP/FM5 SRF Evaluation

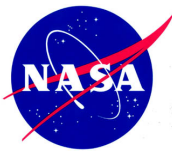
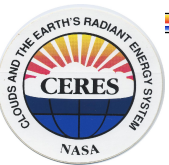
LW Radiance Comparison

2014 Longwave Radiance comparison with the Pre-launch Total SRF

	FM3 (Radiance)	FM5 (Radiance)	% Diff
All-sky all scenes	77.4353	77.2107	-0.2909
All-sky ocean	78.8257	78.663	-0.2068
All-sky land	80.4732	80.1769	-0.3695

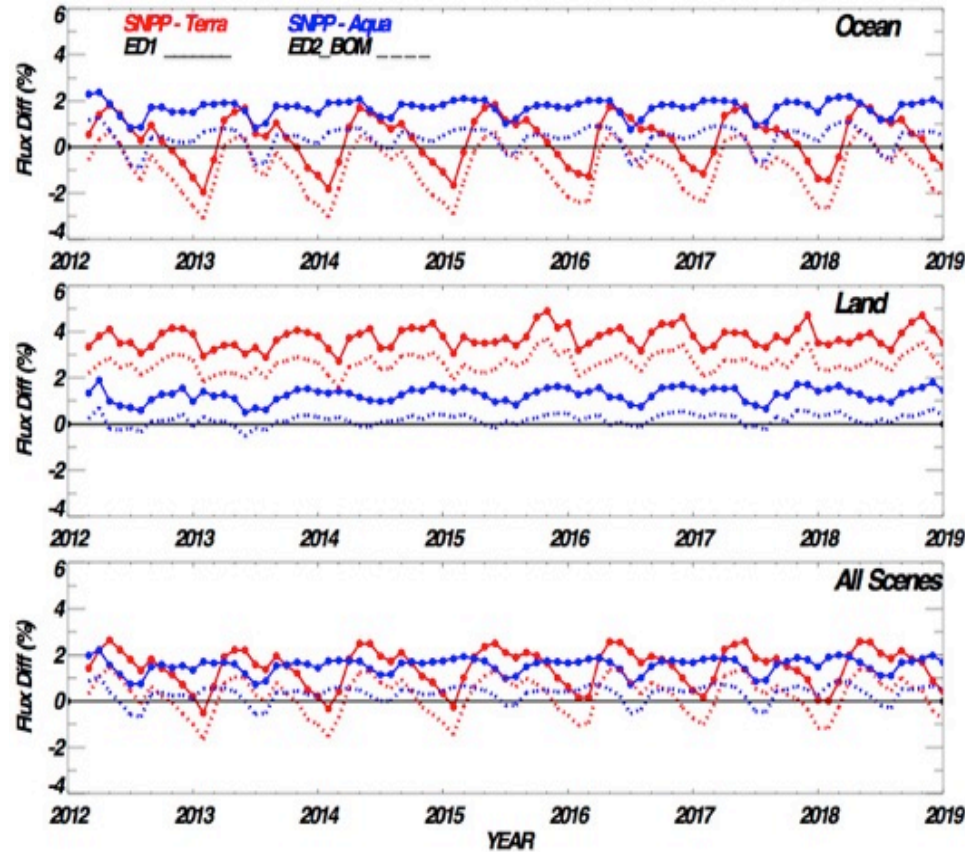
2014 Edition-2 BOM Longwave Radiance Comparison

	FM3 (Radiance)	FM5 (Radiance)	% Diff
All-sky all scenes	77.4353	77.492	0.0732
All-sky ocean	78.8257	78.9476	0.1544
All-sky land	80.4732	80.4785	-0.0066

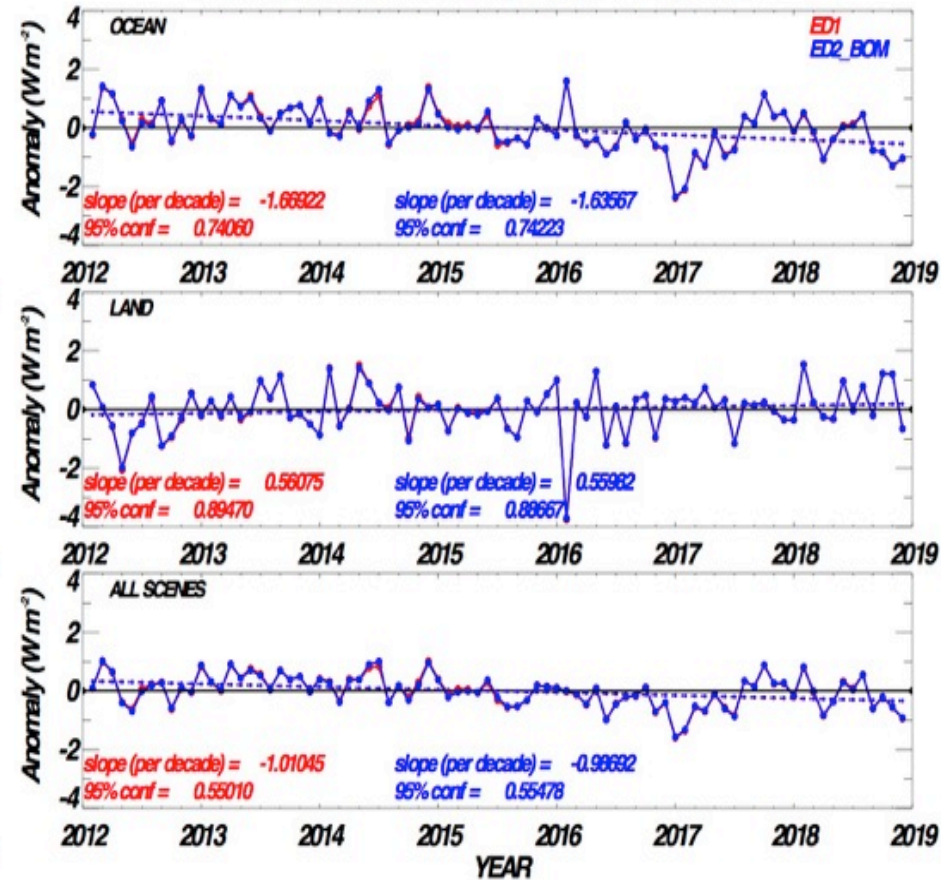


S-NPP/FM5 Edition2 SRF Validation: SW

SW Flux (24h) Difference (SNPP - Terra, Aqua) for All Sky Scenes



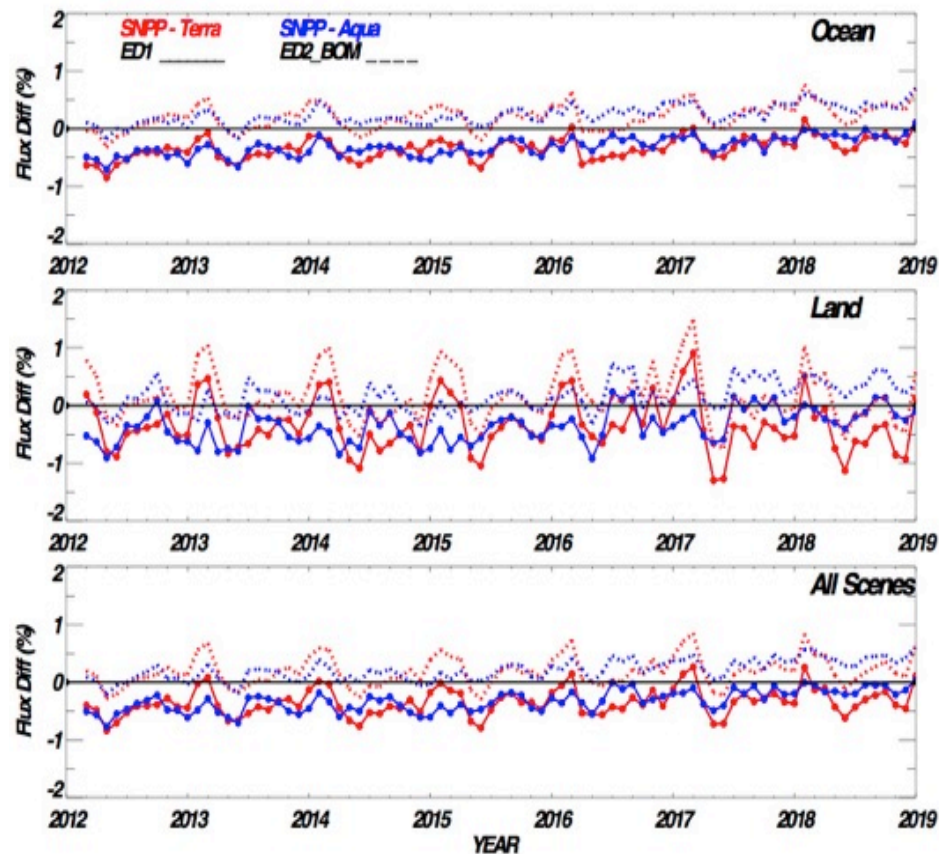
Anomaly of S-NPP SW Flux (24h) for All Sky Scenes



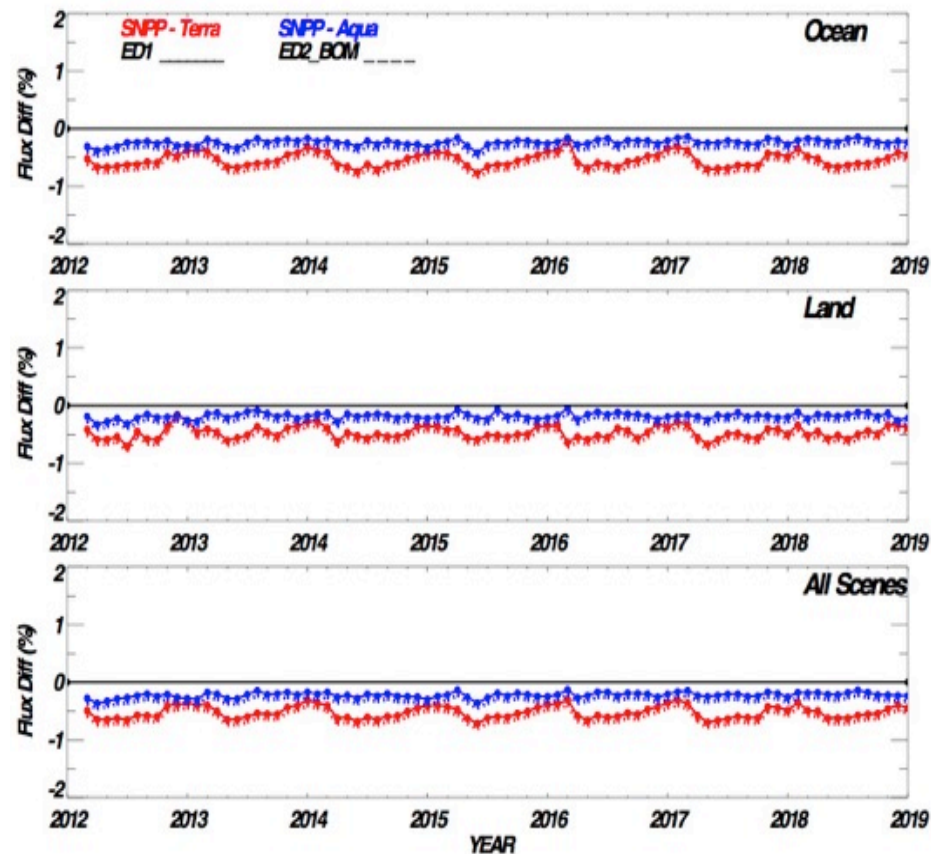
SW comparison with Aqua/FM3 and Terra FM1 show the differences are reduced.
Anomaly trends for Edition1 and Edition2 show similar trend for all scenes.

S-NPP/FM5 Edition2 SRF Validation: LW

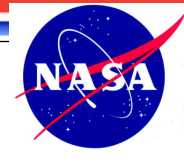
LW(Day) Flux Difference (SNPP - Terra, Aqua) for All Sky Scenes



LW(Night) Flux Difference (SNPP - Terra, Aqua) for All Sky Scenes

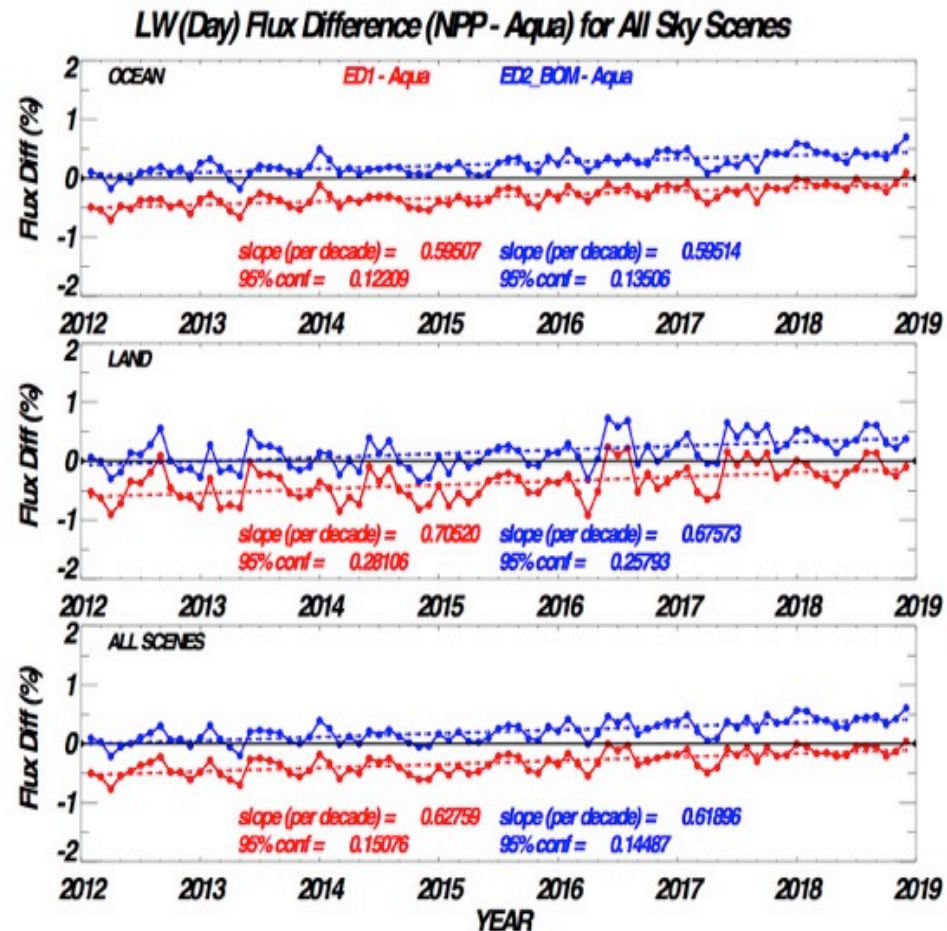
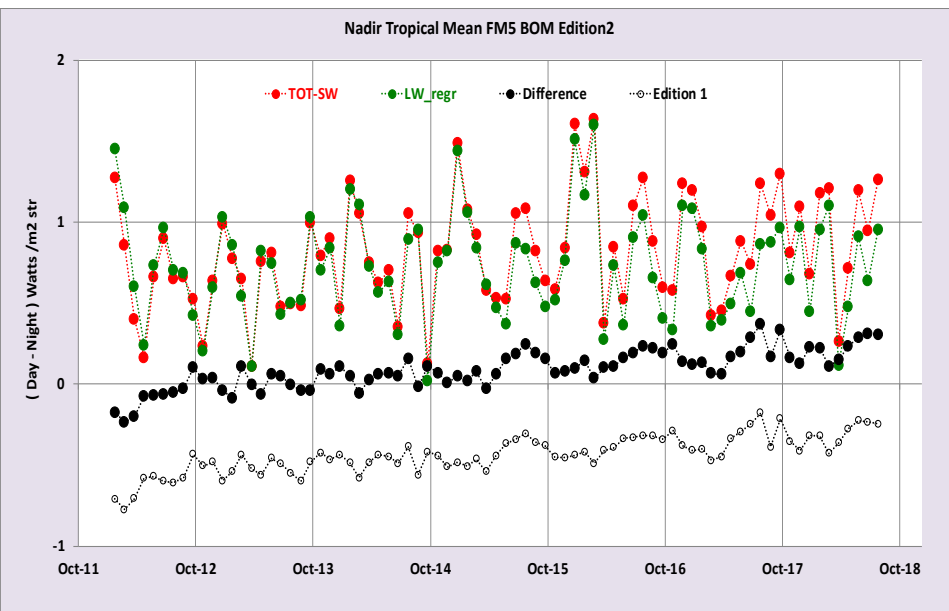


LW-Day comparisons also show the differences were reduced. LW-Night measurements do not show any impact.



S-NPP/FM5: SW/TOT SENSOR Changes

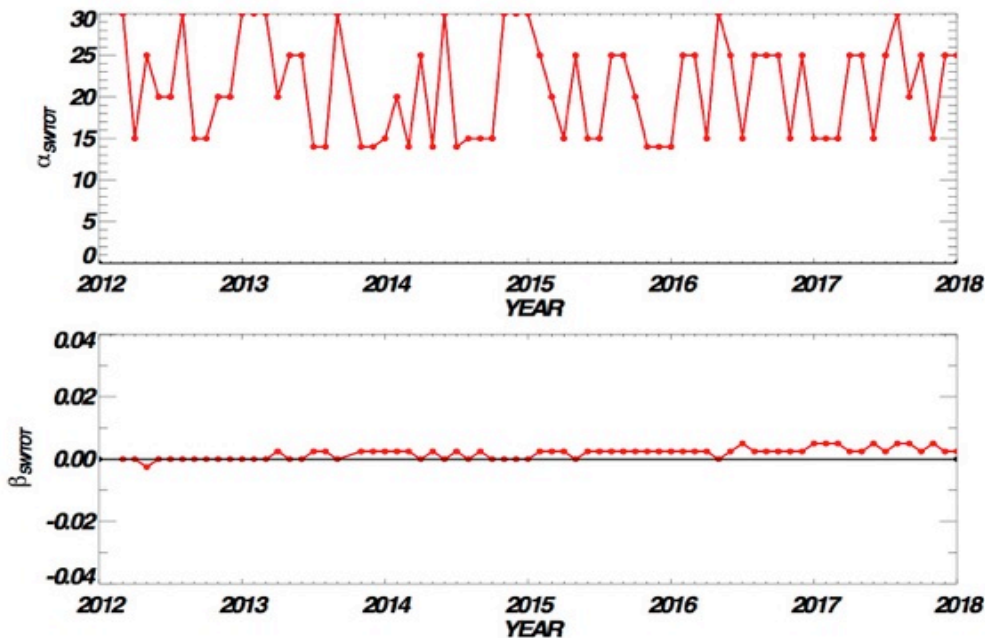
- FM5 LW-day comparison with Aqua and the Tropical Mean study show positive trend of $\sim 0.6\%$ in 7 year period.



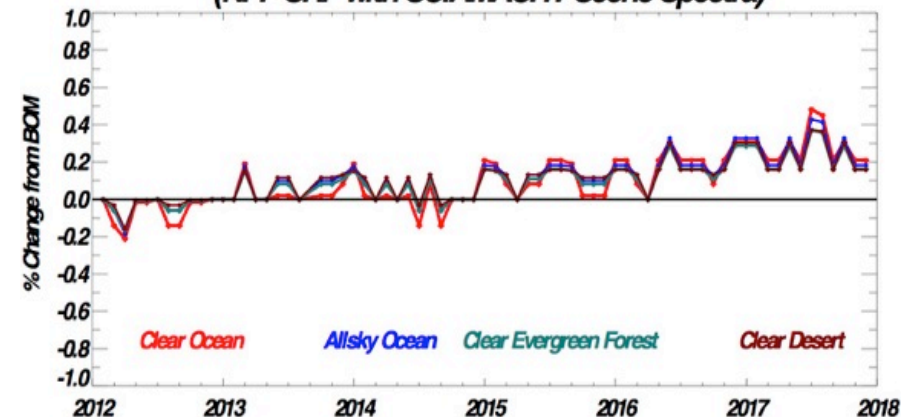
S-NPP/FM5: SW/TOT SENSOR Changes

- Current methodology : Regression between LW(Day-Night) and WN (Day-Night) using Tropical Ocean and Land scenes. The corrections applied to SW/TOT SRF is of the functional form: $D(\lambda) = [1 - e^{-\alpha\lambda}] + \beta$

SW/TOT Coefficients for FM5 ($\alpha_{SW}=30$)



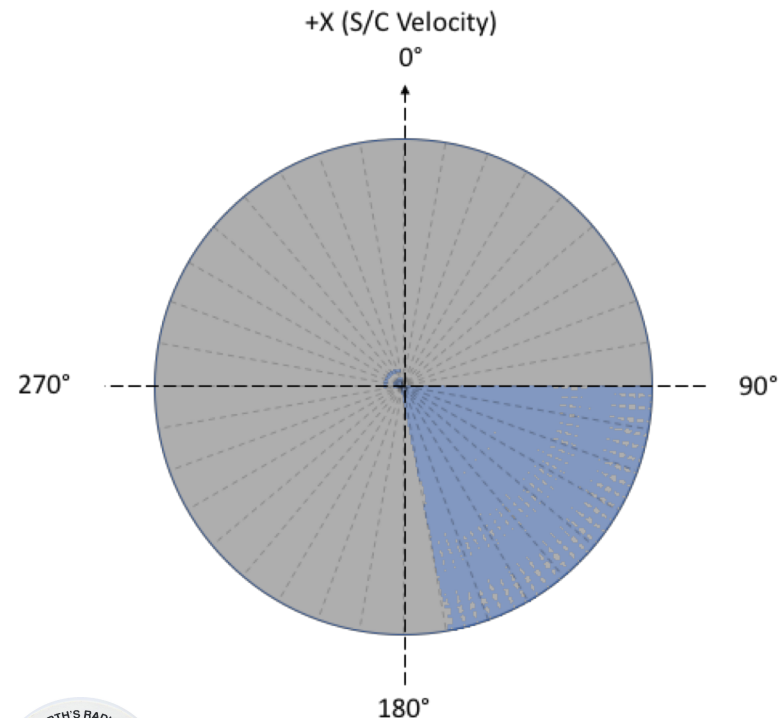
SW/TOT Throughput Change for NPP (ED2 w/ SPOT correction)
(NPP SRF with SCIAMACHY Scene Spectra)



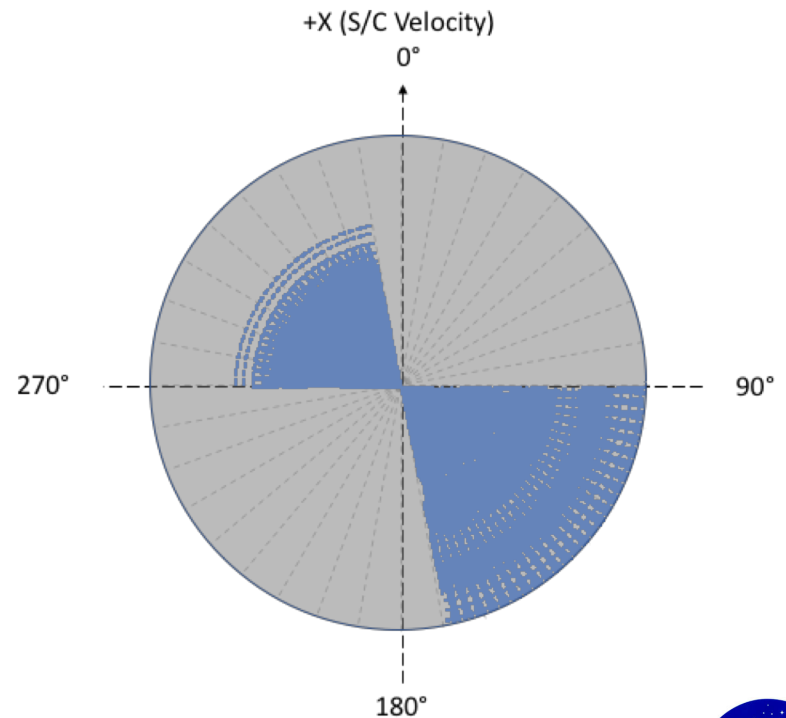
S-NPP/FM5: RAP Mode Operational Planning

- Investigation underway for the data collect options to develop the FM5 ADMs.
- FM3 RAP Data subsetting at restricted clock/cone angles.

Restricted Az, Nadir limit
No RAM or Sun direction exposure



Restricted Az, Short-Earth
Limited RAM & Sun direction exposure



TERRA & AQUA INSTRUMENT STATUS

[CERES FM1 – FM4]

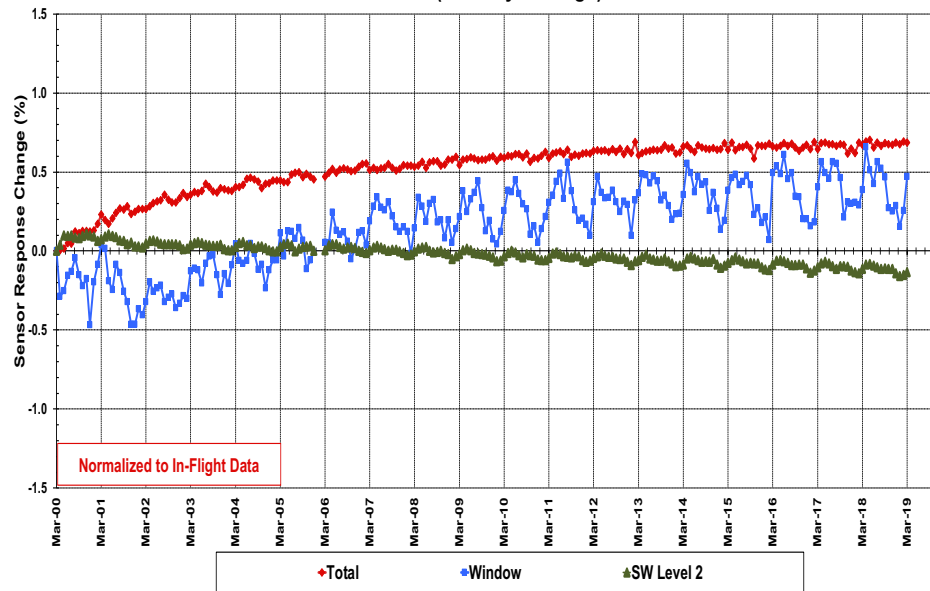
- 1. Calibration: ICM and Solar**
- 2. Validation Results**
- 3. Intercomparisons**



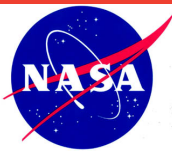
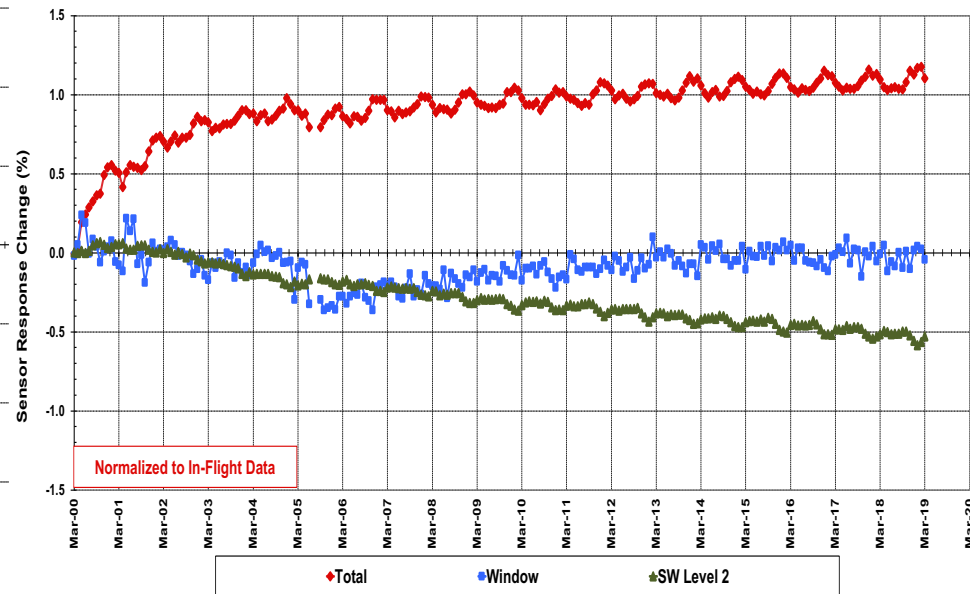
Terra CERES FM1 & FM2 Instrument Calibration

- Increase in response for Total and Window sensors
- Drop in response for SW sensors.

FM1 In-Flight Ed1-CV Internal Calibration Results
(Monthly Average)



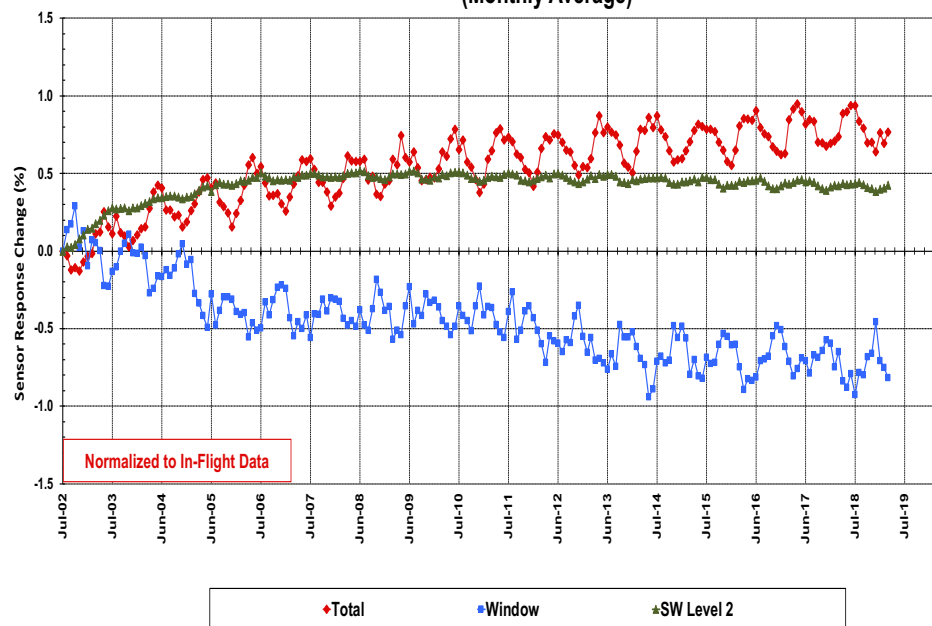
FM2 In-Flight Ed1-CV Internal Calibration Results
(Monthly Average)



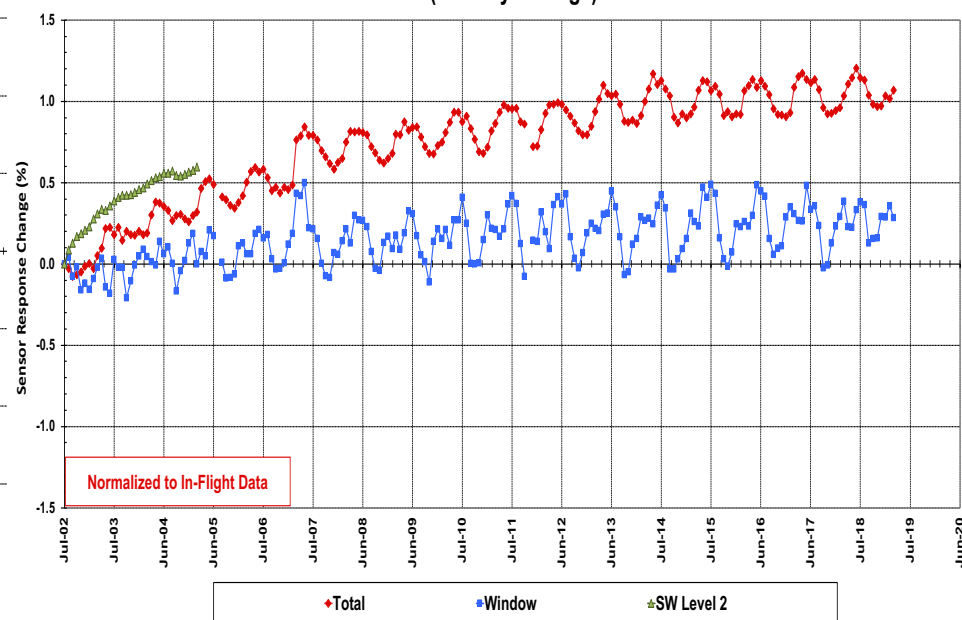
Aqua CERES FM3 & FM4 Instrument Calibration

- Increase in response for Total and SW sensors.
- Window sensor on FM3 showed a drop where as FM4 response show slight upward trend, similar to FM1 and FM2 instruments.

FM3 In-Flight Ed1-CV Internal Calibration Results
(Monthly Average)



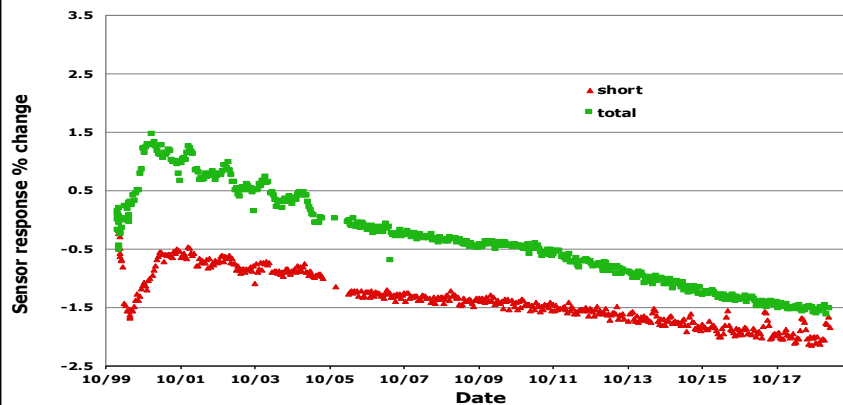
FM4 In-Flight Ed1-CV Internal Calibration Results
(Monthly Average)



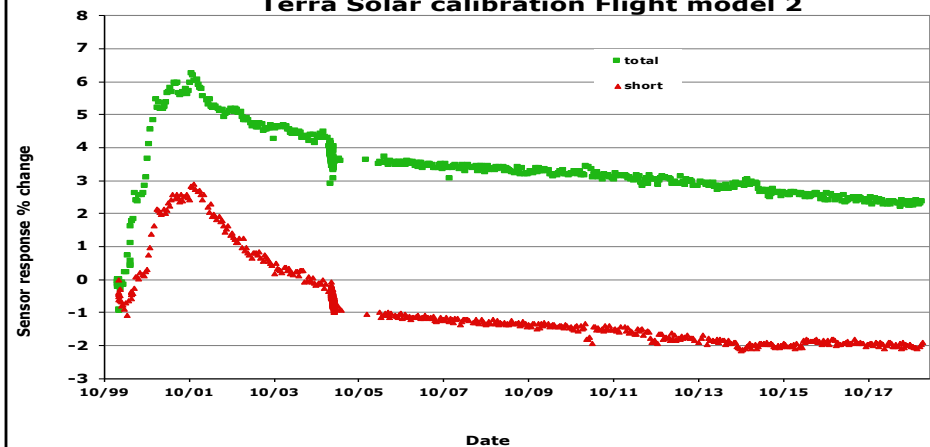
Terra & Aqua Solar Calibration Results

- After the new solar raster scan calibration sequence starting April 2006, the MAMs showed similar rate of change – 1% for SW sensors and 1.5 to 2.0% for Total sensors.

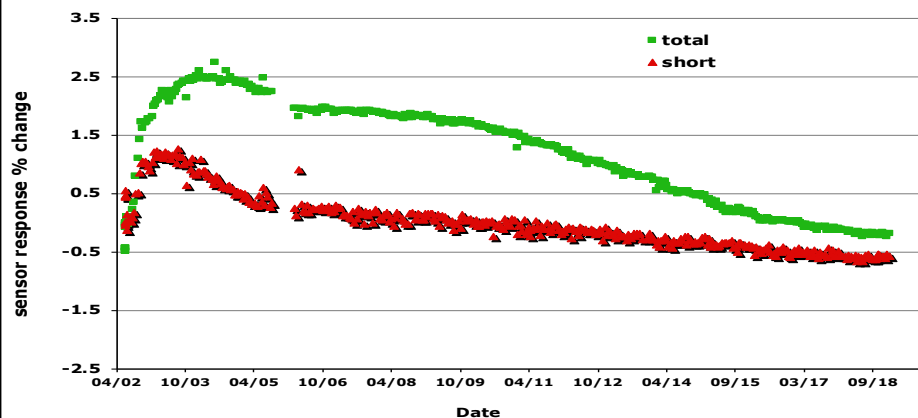
Terra Solar Calibration Flight model 1



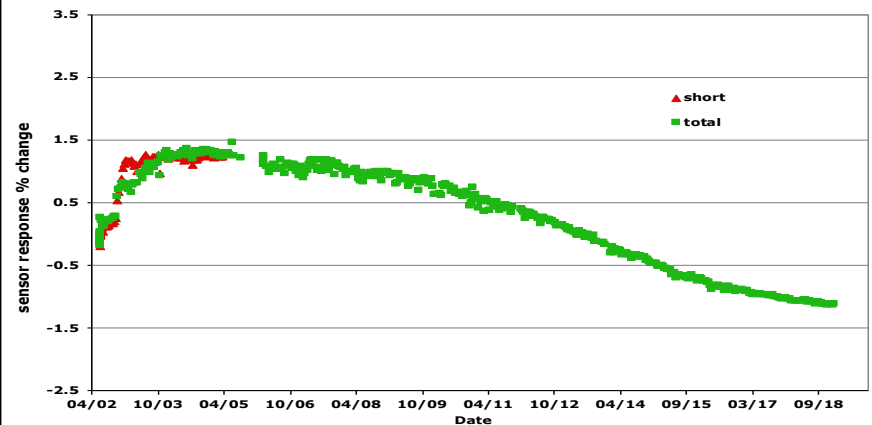
Terra Solar calibration Flight model 2



AQUA Solar calibration Flight model3

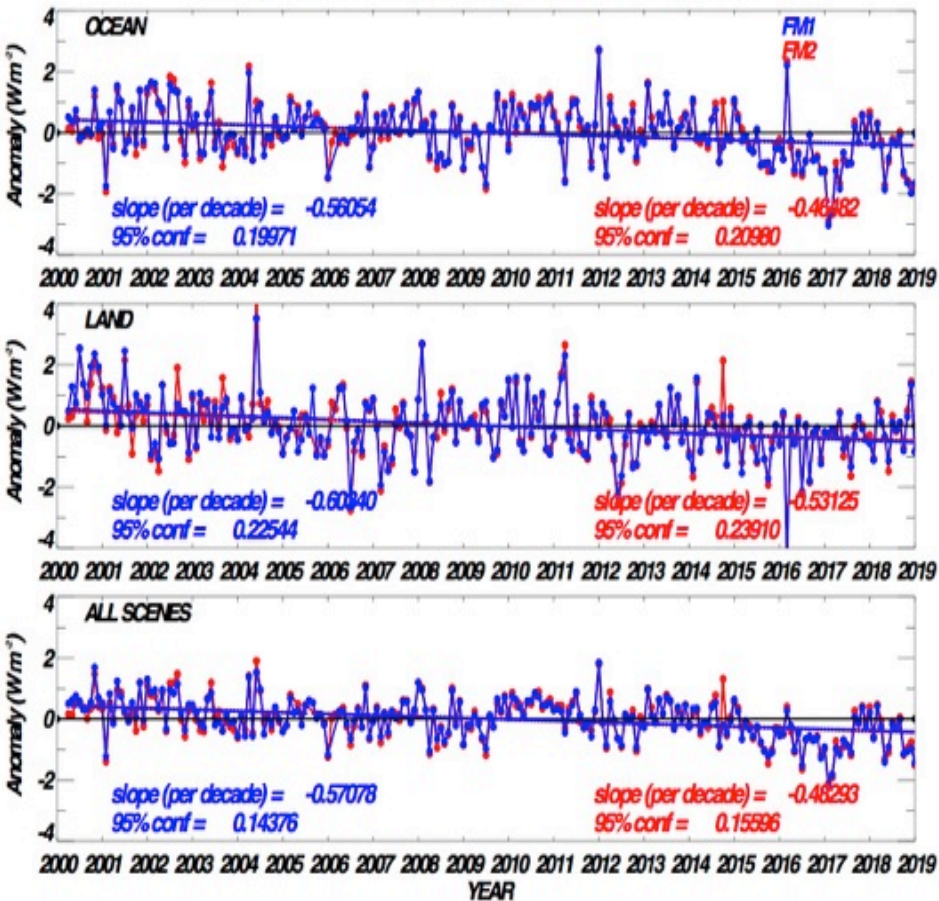


AQUA Solar calibration Flight model 4

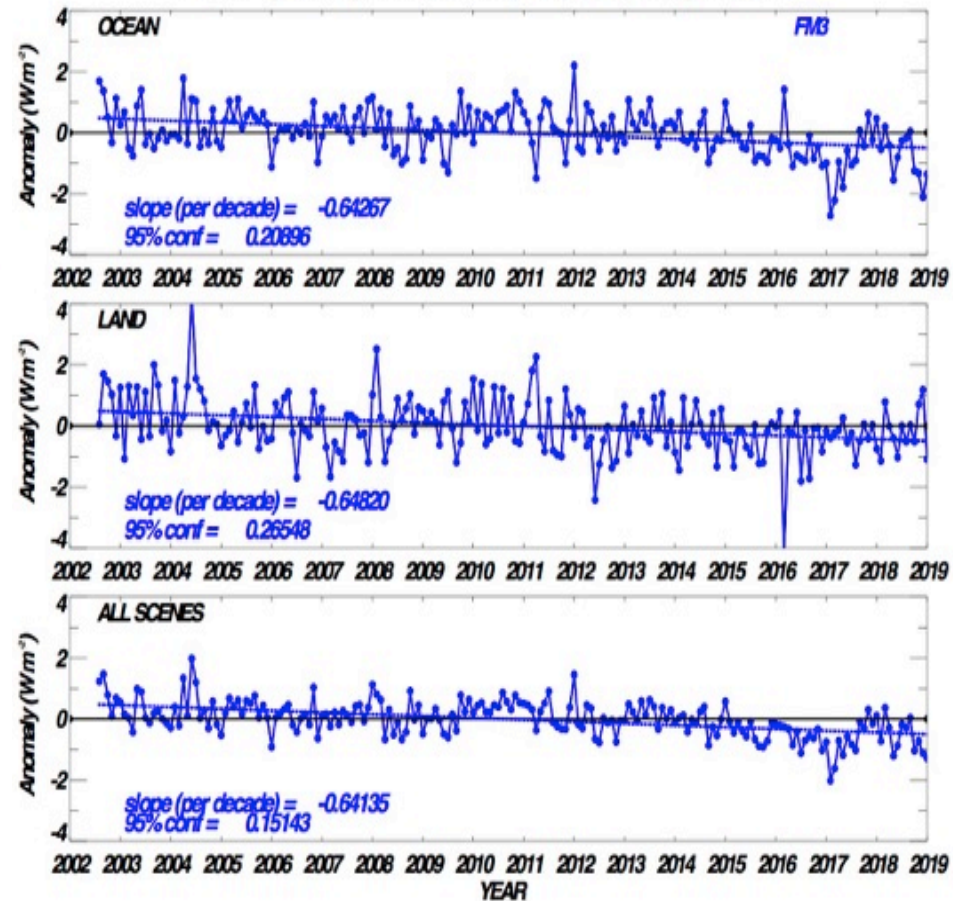


EDITION-4 Validation: TERRA & AQUA SW Sensors

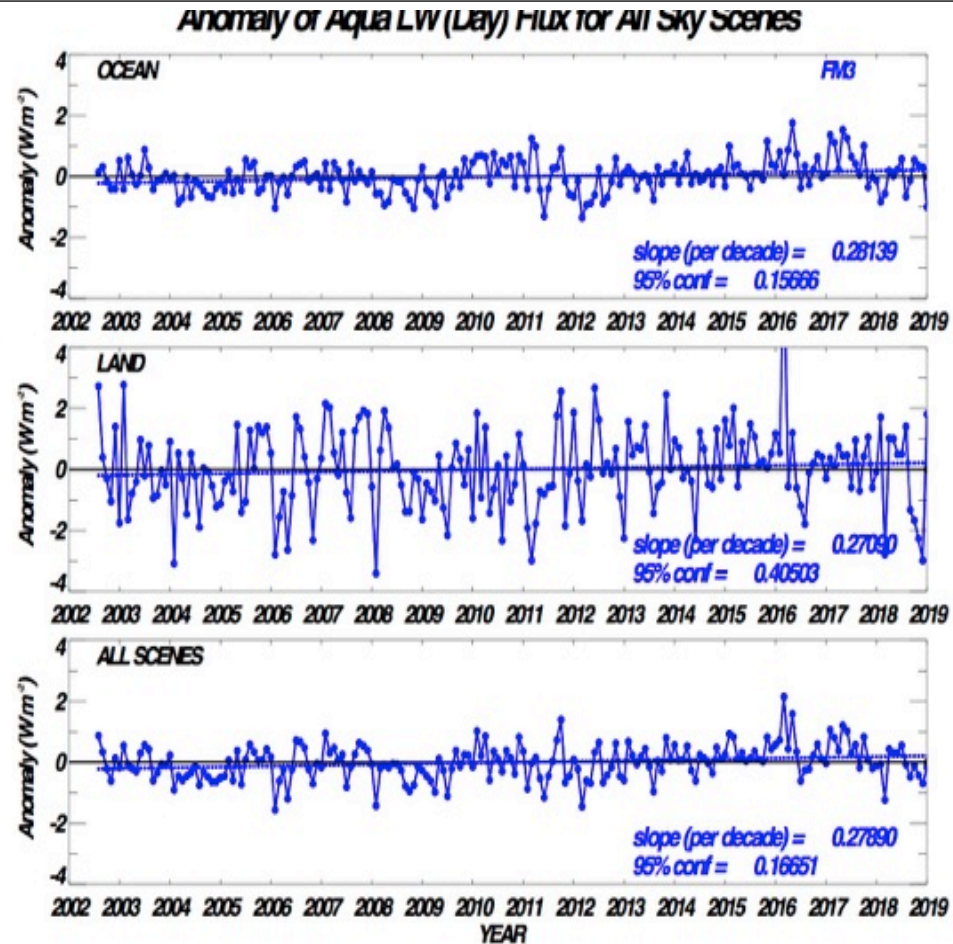
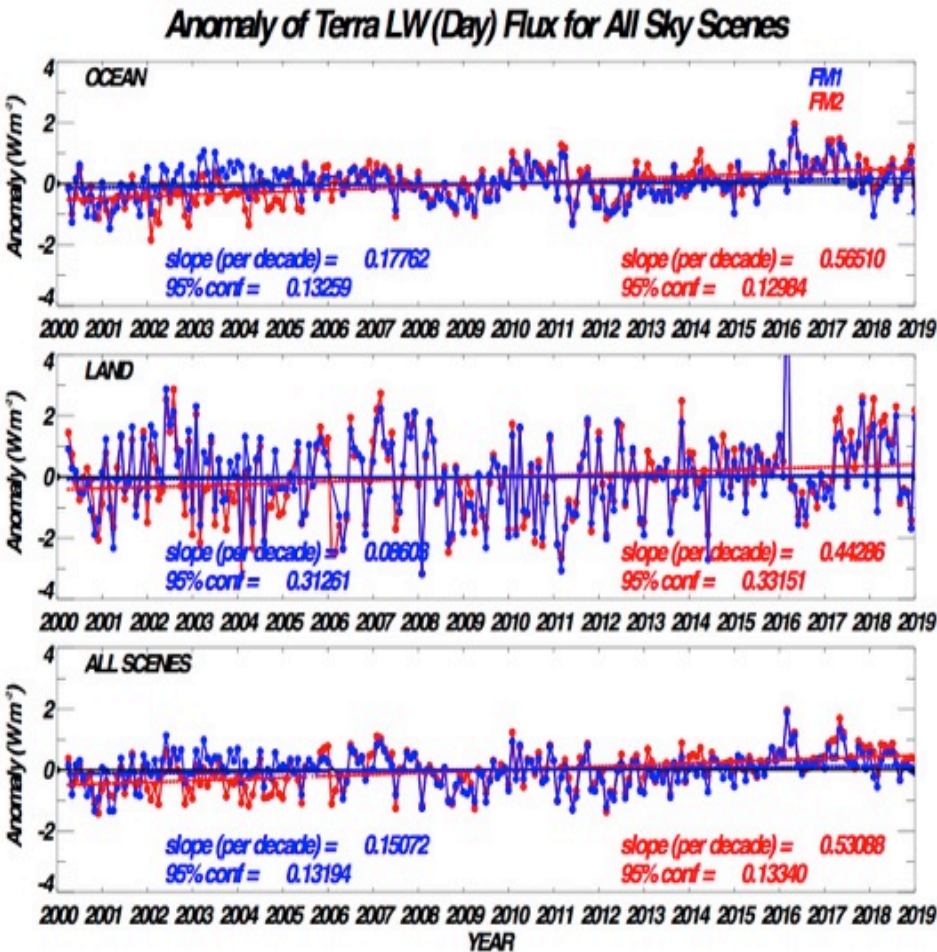
Anomaly of Terra SW Flux (24h) for All Sky Scenes



Anomaly of Aqua SW Flux (24h) for All Sky Scenes



EDITION-4 Validation: TERRA & AQUA LW_Day Flux



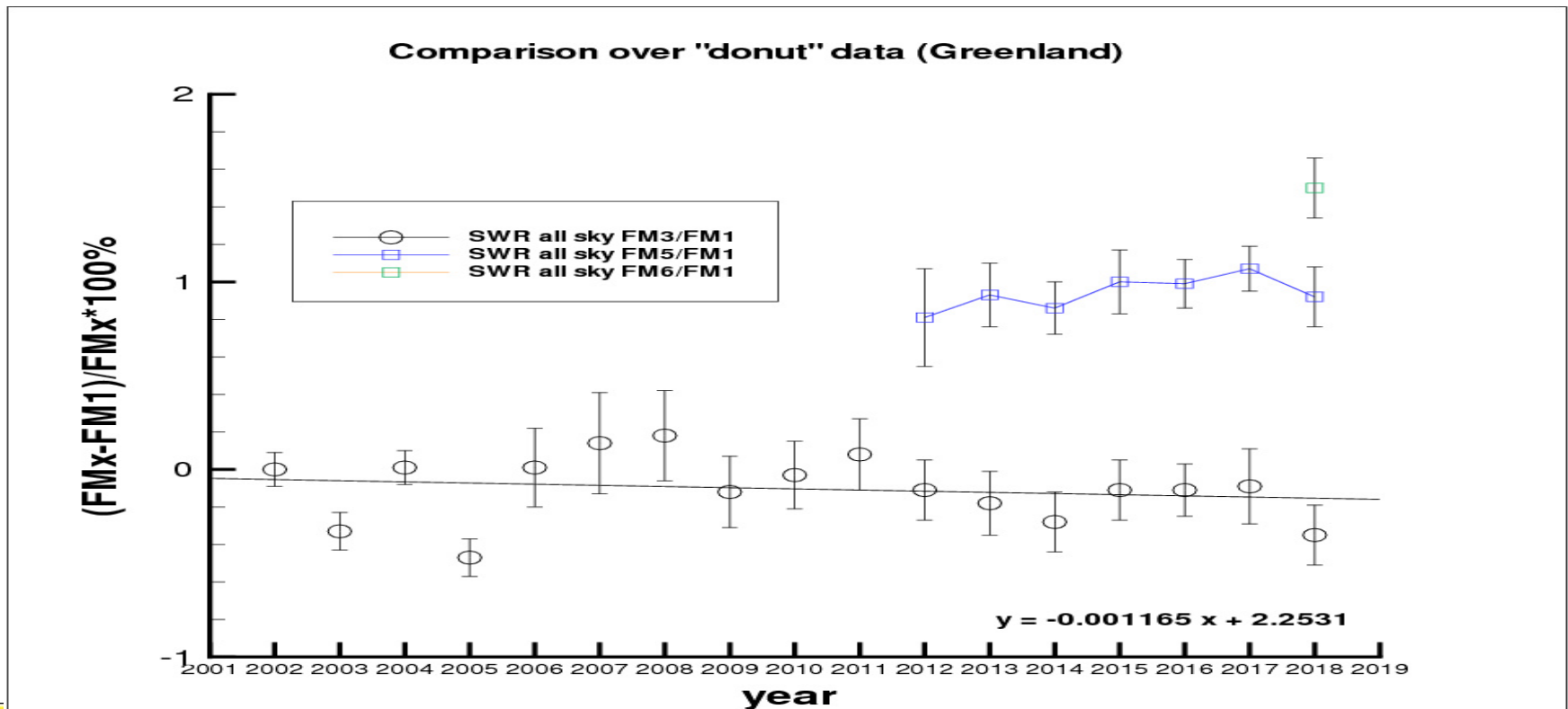
LW Flux anomaly for all scenes show similar trend for all instruments.

Comparison of FM6/FM5/FM3 with FM1

Minor Plane Scan(Greenland)

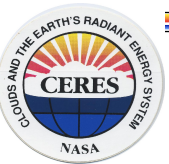
$$\Delta\text{RAZ} < 10^\circ; \Delta\text{VZA} < 10^\circ$$

Edition 4 for FM3; Edition 1 for FM5; Edition 1-CV for FM6



SUMMARY

- CERES FM6 instrument performance is stable after the initial sensor response increase in Total and Shortwave sensor. The ICM and Solar calibration results show good agreement.
- CERES FM5 Start of Mission Spectral Response Function (SRF) was completed to bring S-NPP/FM5 and Aqua/FM3 to common radiometric scale. A Lagrange optimization method was used to determine the necessary corrections for SW sensor measurement.
- The Terra and Aqua Instruments' Gains and Spectral Response Functions for Edition4 processing were delivered through December 2018. Validation results of Terra/Aqua Edition-4 data show consistent trends among the three CERES instruments (FM1 – FM3).



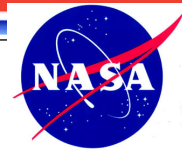
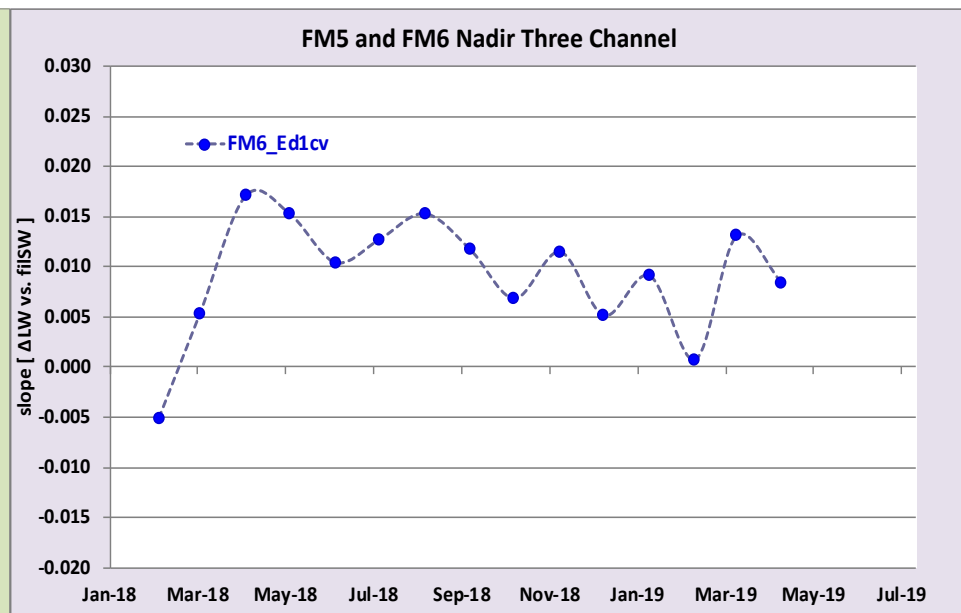
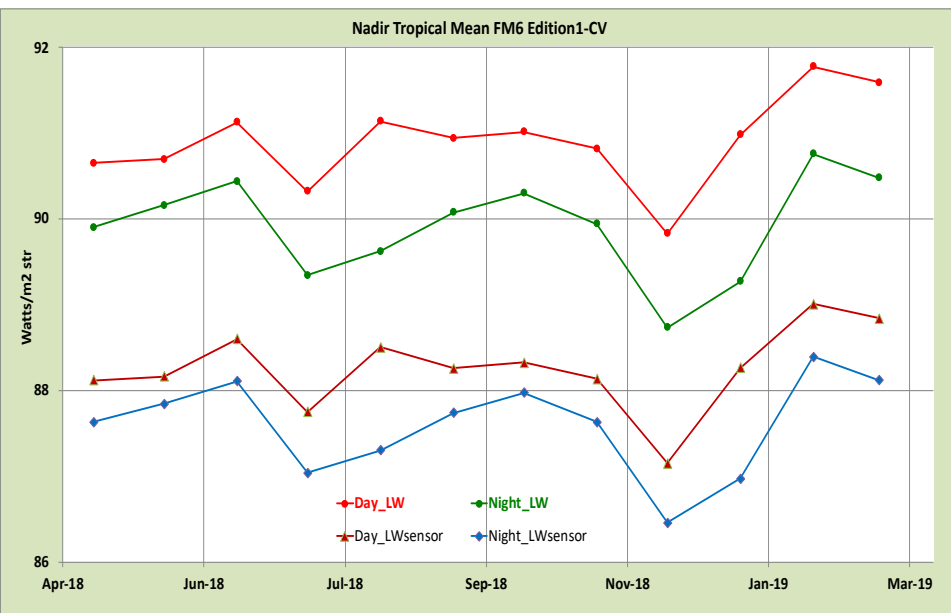
BACK UP SLIDES

JPSS-1/CERES FM6 Validation – 3 Channel Compare

Tropical Mean (TM): Nadir LW radiance for All-sky Ocean in ± 20 deg Latitude.

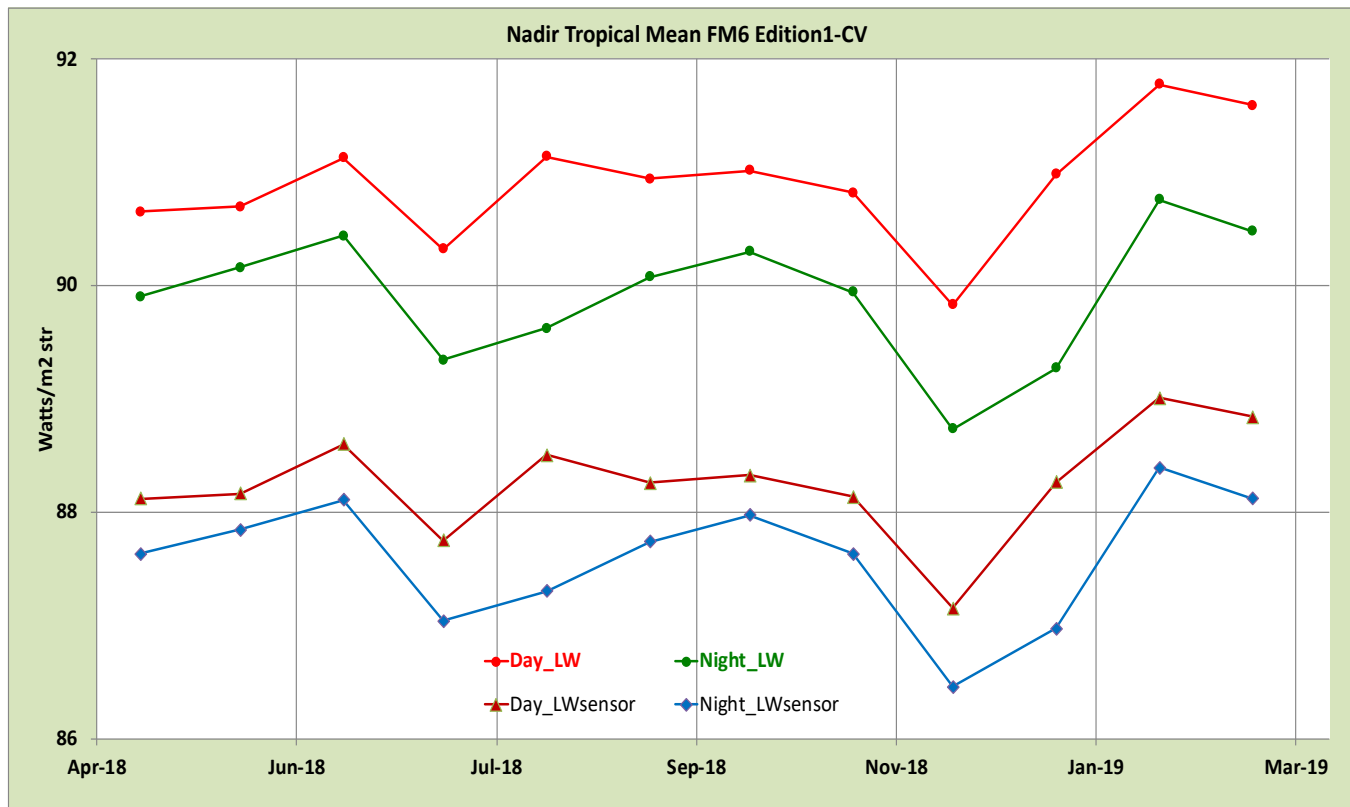
Day and Night TM values from both Total and Longwave channels are trended.

Three Channel comparison use Deep Convective Cloud (DCC) as target. Trend in monthly slope between delta LW and SW measurements is monitored. The results show slight downward trend over time.

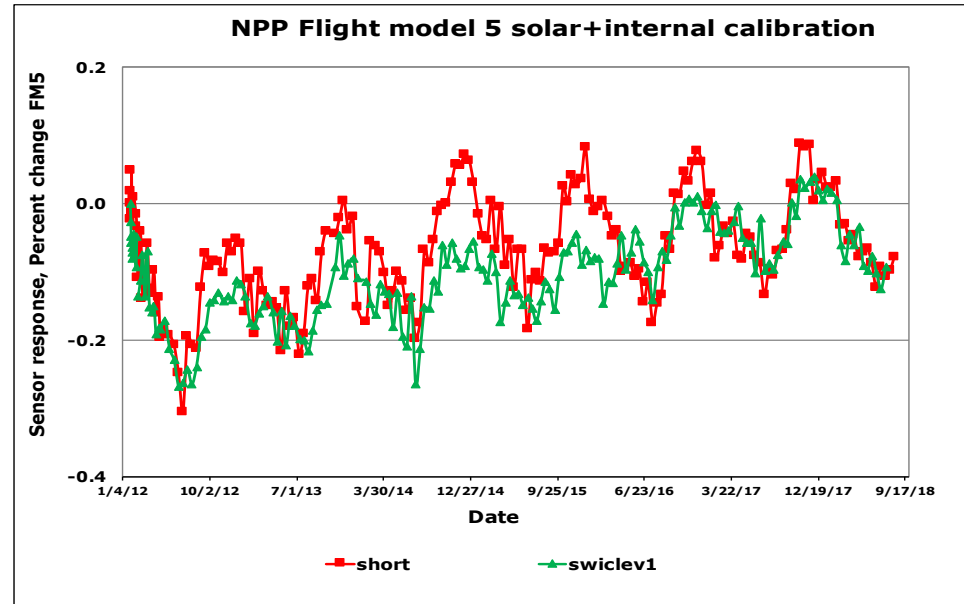
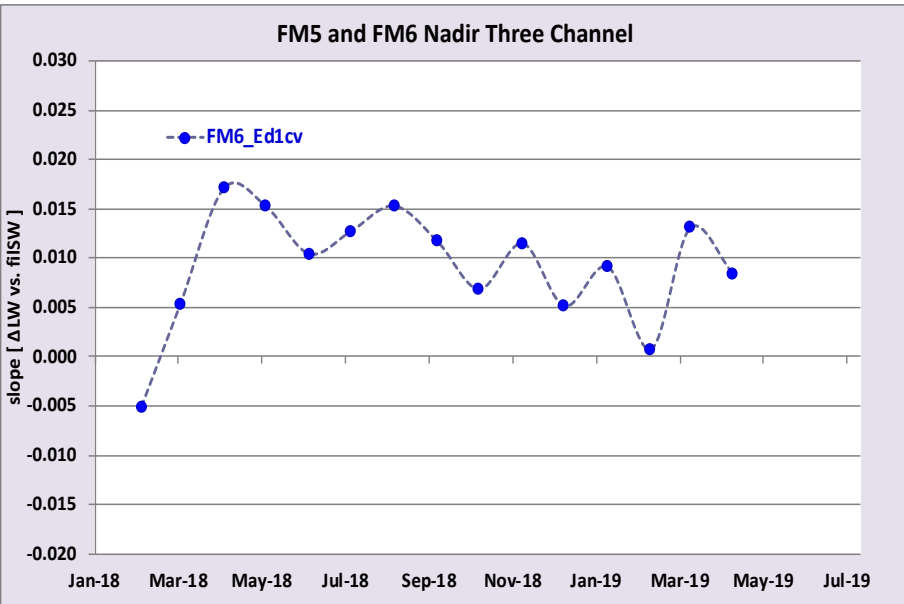


S-NPP/CERES FM5 Instrument Calibration

Comparison of calibration results from SWICS (Level1) and MAM showed similar trends in the SW sensor.



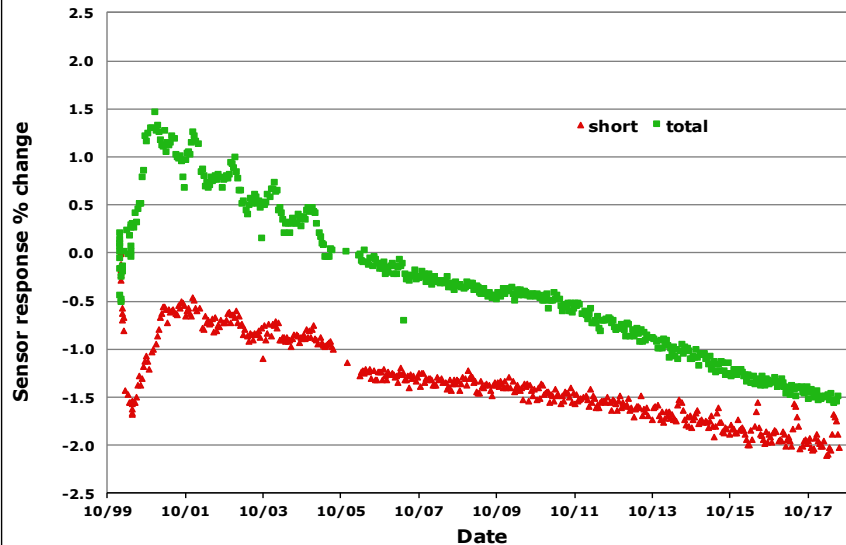
Terra FM1 & FM2 Solar Calibration Results



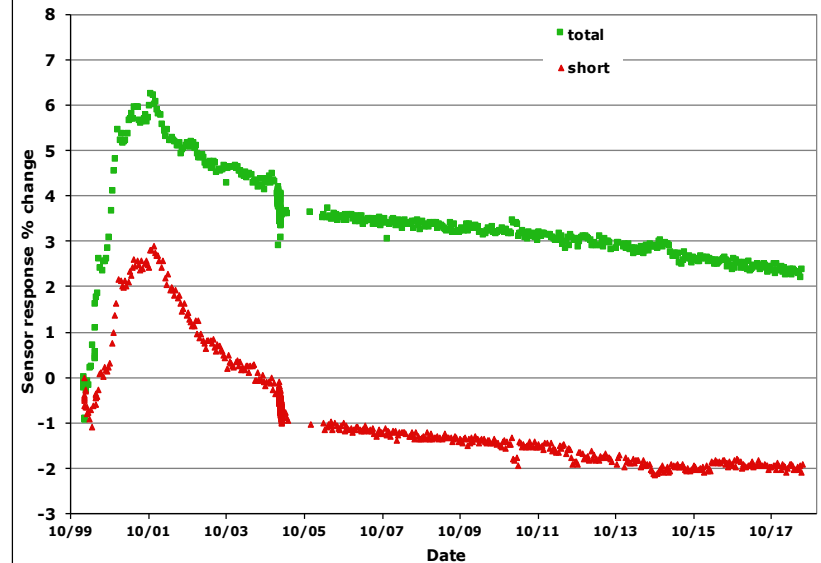
- After rapid throughput change in first 4 years, Mirror Attenuator Mosaics (MAMs) on FM1 & FM2 instruments show slower rate of change.
- After the new solar raster scan calibration sequence starting Dec 2005, the MAMs showed similar rate of change in both instruments.

Aqua FM3 & FM4 Solar Calibration Results

Terra Solar Calibration Flight model 1



Terra Solar calibration Flight model 2



- Mirror Attenuator Mosaics (MAMs) on FM3 & FM4 instruments also showed increase in throughput for first 18 months in Mission.
- The total sensor responses on both instruments showed a drop of 2 percent after the new solar raster scan calibration sequence started in Dec 2005.
- SW sensor on FM3 instrument showed about one percent drop in response.

JPSS-1/FM6 Intercomparisons

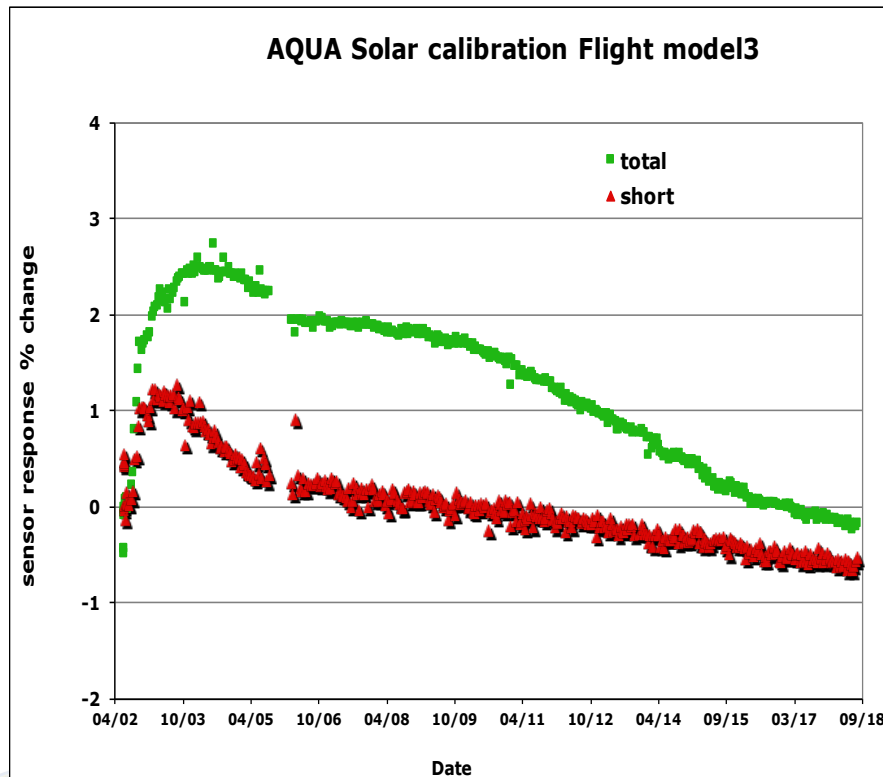
Minor Plane Radiance Measurement:

FM1 and FM6 align their scans in a plane perpendicular to local solar plane.

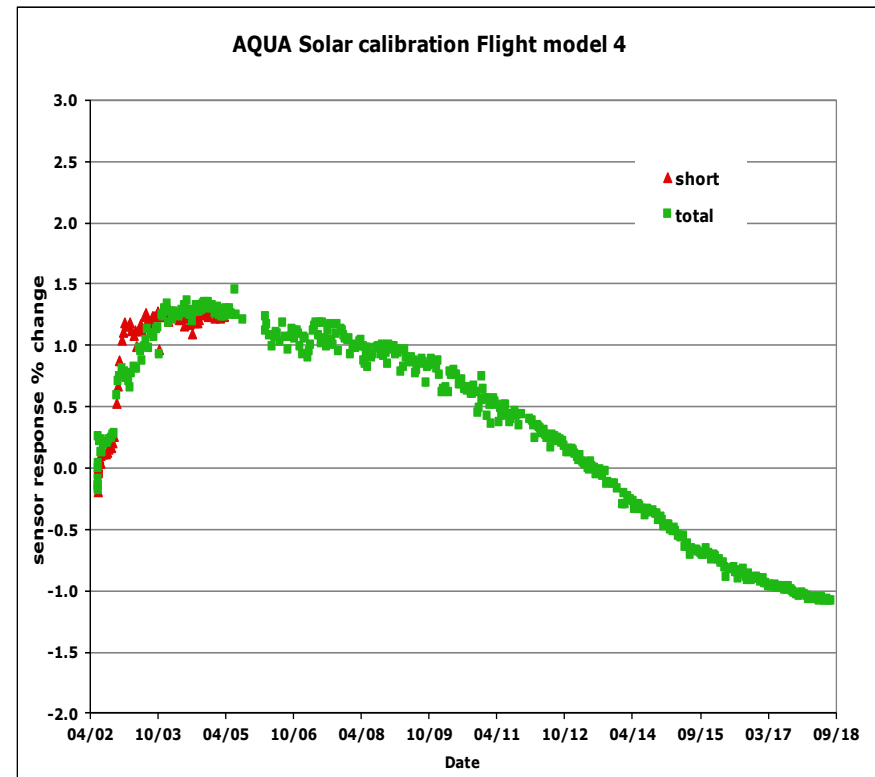
Location: 70° N Time differential for FM1 - FM6 < 5min every 64 hours.

Scanning Pattern in the Minor Plane on June 21, 2018

FM6



FM1



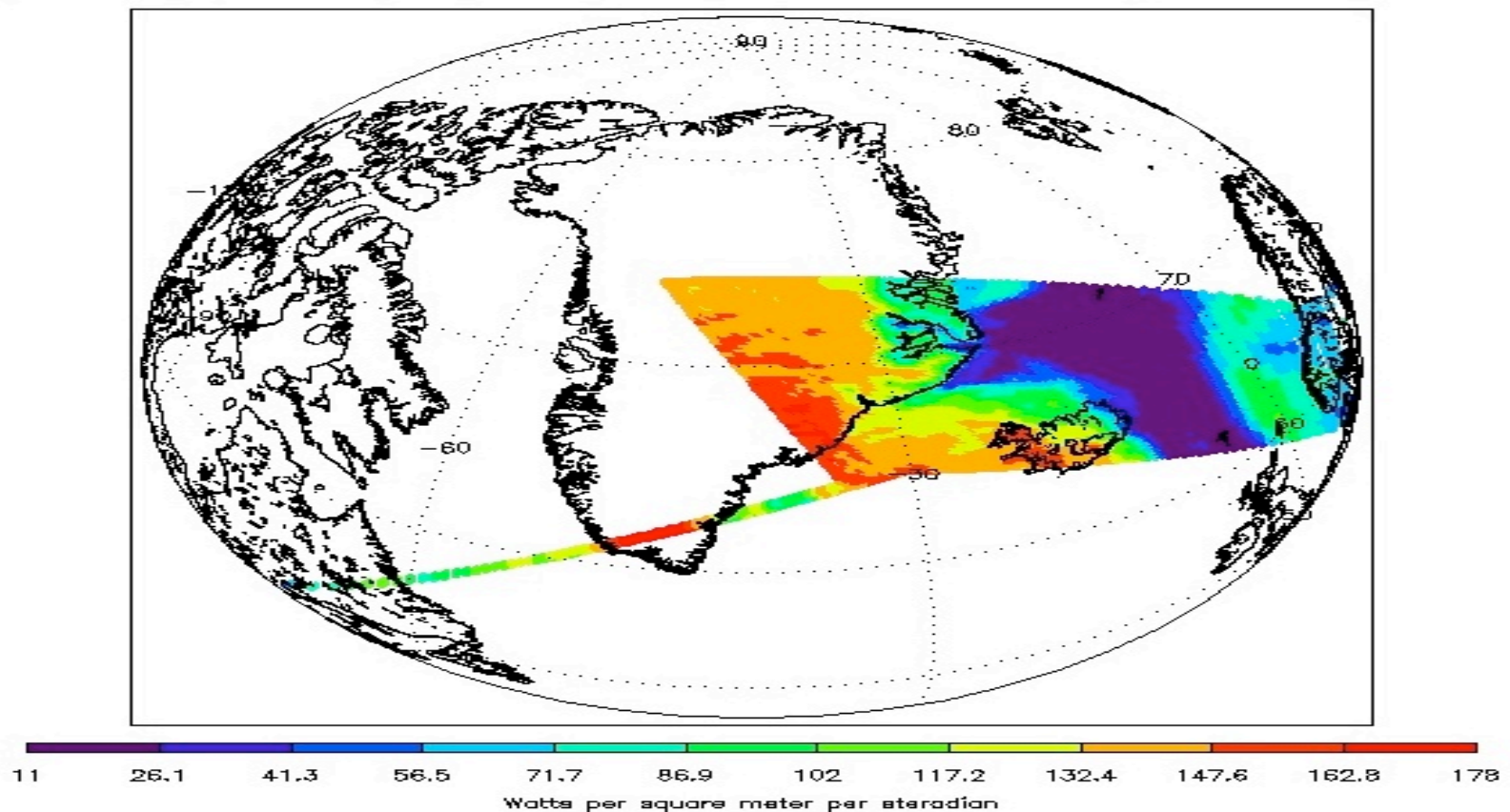
Lagrange Multiplier solution

- Table shows the SW measurement uncertainty for FM5.

Wavelength Band (nm)	FM5 SW Measurement Uncertainty 2-sigma (%)
420	1.9
460	1.3
520	0.9
620	0.1
720	0.1
810	0.3
900	0.1
1000	0.2
1140	0.3
1260	0.5
1350	0.7
1640	1
1920	1

JPSS-1/CERES FM6 Instrument Calibration

Internal Calibration Module (ICM) and Solar calibration results for Total and Shortwave sensors show similar trends.



FM5/FM3 Differences for 2014

All Sky	Year	N	Aqua	NPP	Dif Std	Abs Dif	Rel Dif
Ed1	2014	136	0.2939	0.2979	0.0011	0.0040±0.0002	1.37±0.06%
Ed2-V01	2014	136	0.2939	0.2960	0.0009	0.0022±0.0002	0.74±0.05%

Clear Ocn	Year	N	Aqua	NPP	Dif Std	Abs Dif	Rel Dif
Ed1	2014	111	0.0615	0.0633	0.0009	0.0018±0.0002	2.97±0.29%
Ed2-V01	2014	111	0.0615	0.0623	0.0009	0.0008±0.0002	1.34±0.28%

Clear Lnd	Year	N	Aqua	NPP	Dif Std	Abs Dif	Rel Dif
Ed1	2014	71	0.2222	0.2242	0.0015	0.0021±0.0004	0.94±0.16%
Ed2-V01	2014	71	0.2222	0.2231	0.0014	0.0010±0.0003	0.43±0.15%

Direct compare of FM5 and FM3

FM5–FM3 “simultaneous Earth” observation

2012/2013/2014/2015/2016

$\Delta\text{Time} < 1\text{min}$; $\Delta\text{RAZ} < 10^\circ$; $\Delta\text{VZA} < 10^\circ$

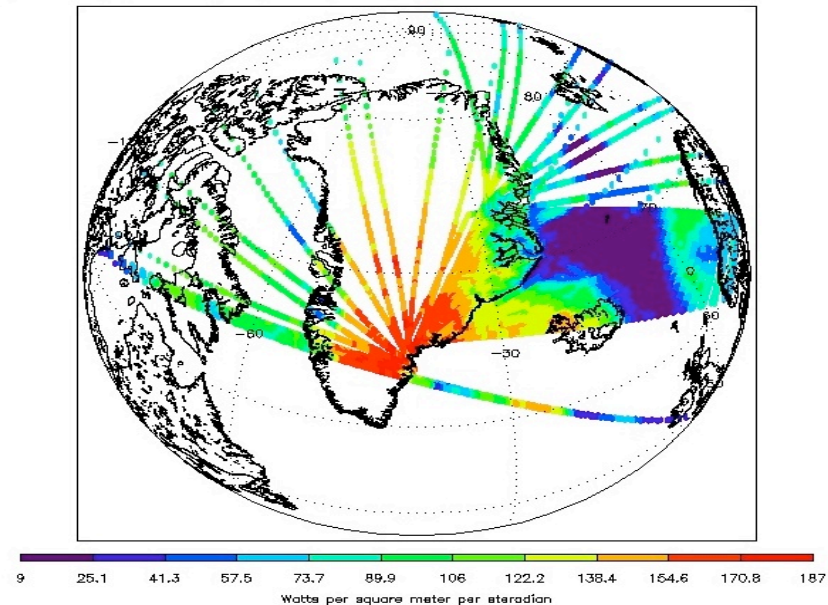
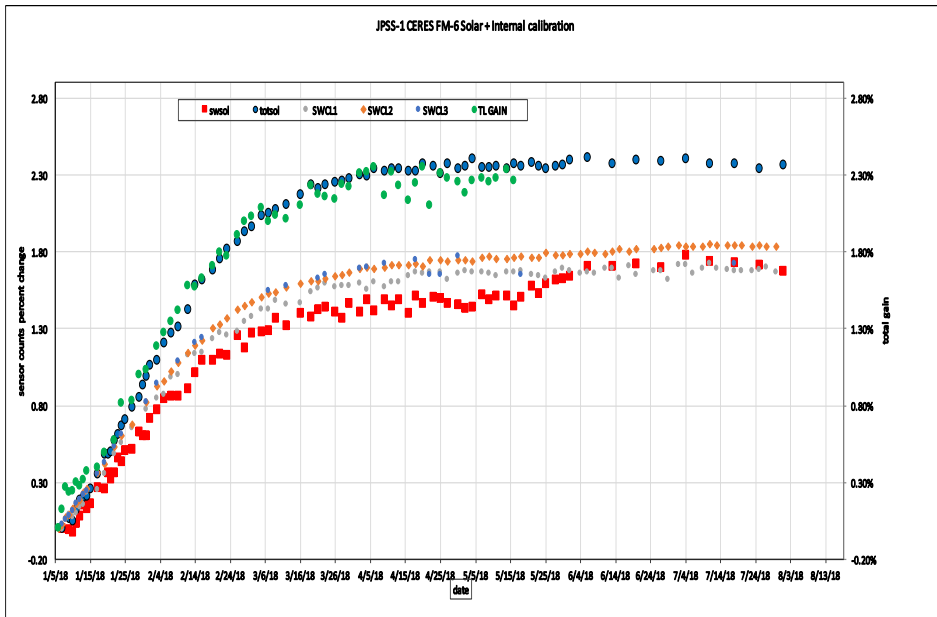
All-sky

Shown differences are statistically significant

(FM5-FM3)/FM5	FM5 Radiance [W m ⁻² sr ⁻¹]	Relative Error [%]	α -confidence [95%]	Number of samples
Shortwave	79 /85 /77 /81 /80	3.3 / 2.7 / 1.0/ 1.7 /2.6	.4 /.3 /.4 /.4 /.3	65/86/91/85/91
LW daytime	76 /74 /77 /77 /76	-1.1 /-1.3 /-0.6 /-0.9 /-1.0	.1 /.1 /.1 /.1 /.1	69/89/91/85/91
LW nighttime	66 /65 /68 /66 /66	-0.3 /-0.3 /0.0 /-0.2 /-0.3	.1 /.1 /.1 /.1 /.1	87/105/106/105/111

- Shown differences are computed as “average of differences” to avoid error cancellation

CERES S-NPP/FM5 – Aqua/FM3 Comparison



Tropical Mean LW Radiances (Day and Night) show minimal differences.
Global Flux Differences show that FM5 SW measurements are higher by $\sim 1.5 \text{ Wm}^{-2}$ and LW measurements lower by $\sim 0.5 \text{ Wm}^{-2}$.

TERRA/AQUA Edition4 GAIN and SRF

- **Edition4 Gains and Spectral Response Functions (SRF) :
Terra and Aqua - Start of Mission to May 2018**
- **The monthly Gain values for the Total, Window and Shortwave sensors are based on in-flight ICM calibrations.**
- **With both instruments on the spacecraft operating in crosstrack mode, the current monthly SRF corrections for SW sensor remain constant.**
- **SRF correction in SW/TOT sensor is calculated monthly using All-sky Ocean and Land measurements of LW and Window sensors.**



EDITION-4 Results: TERRA & AQUA LW_Night Flux

